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Sanitary Sewer Overflows and Sewer System Maintenance

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SUMMARY

The Charlotte-Mecklenburg Utilities (CMU) of North Carolina has maintained an SSO database under their Complaint History And Maintenance Processing System (CHAMPS) for at least 15 years. This database provides detailed information on each reported SSO and all the sewer system maintenance activities under CMU's jurisdiction. This database, along with several other data sources, formed a supporting ground to study the relationship between the monthly SSO frequency and several major SSO factors, with an emphasis on the impact of pro-active sewer system maintenance activities.

The statistical relationship, between the SSO frequency and the levels of its factors, was gauged by a Poisson Regression Model.

The study results support the following statements:

1. The seasonal change of the sewer system condition is the single most powerful factor in explaining the fluctuation of the SSO frequency in time. It explains approximately 24.1% of the total variation in the observed SSO occurrences.

2. A higher level of pro-active sewer system maintenance activities lowers the SSO frequency. The maintenance activity factor explains approximately 16.42% of the total SSO variation in time. This fact establishes a qualitative as well as a quantitative relationship between pro-active sewer maintenance activities and SSO frequency.

3. The total wastewater flow to the treatment plants, a measure of the system load, is also explanatory. It explains approximately 9.2% of the total variation of SSO in time. The impact of the flow does not seem to be as strong as that of seasonal change or that of pro-active maintenance activities.

4. A maintenance program with an intelligent scheduling mechanism lowers the SSO frequency. The Schaaf-like scheduling methodology adopted by CMU explains approximately 4.48% of the total SSO variation in time.

5. The total impact of human effort to improve the sewer condition (pro-active maintenance activities and intelligent scheduling methodologies) is less than the impact by the seasonal changes. The numerical comparison is 20.9% versus 24.1%.

6. Given the mixture of the maintenance activities at CMU for the last fourteen years, the study suggests a ranking of maintenance types by their relative strengths (RS) in reducing the frequency of SSO. The ranking * is:

   a) Rapid Response (RS=30.16%),
   b) Scheduled Inspection (RS=20.41%),
   c) Rodder (Root Removal) (RS=16.42%),
   d) Right-of-Way Mowing (RS=12.18%),
   e) Herbicide Application (RS=11.78%),
   f) Off-Street Maintenance (RS=10.58%),
   g) T.V. (RS=0.44%),
   h) Jets & Combination Machines (high pressure water jets) (RS=-2.66%), and
   I) Manhole Inspection and Cleaning (RS=-3.07%).

7. While all the above statements are strongly supported by statistical evidence from the CMU data, the final regression model only explains approximately 64.05% of the total variation. This fact suggests that while we can identify and even quantify some of the major SSO factors with statistical confidence, there is still 35.95% of the SSO fluctuation unexplained.

8. The unexplained SSO variation, along with the fact that human controlled activities are associated with only 20.9% of the total fluctuation, suggest that some of the common beliefs regarding Type *B*** SSOs should be re-examined. In particular, the belief, that SSOs will be controlled if the flow to the system is controlled, needs to be seriously re-considered. The study results suggest that only 9.2% of the SSO problem may be attributed to the flow in the system. Another prevalent belief regarding SSOs is that SSOs can be controlled if a "reasonable maintenance program" is in place. This study suggests that the intensity level of such a "reasonable maintenance program" may be quite a distance away

from the current intensity level in practice.

All the above statements are made based on the inferences drawn from the statistical models employed. Since any statistical model is, at its best, an approximation to the true state of nature, these statements should not be taken as final conclusions, but as mere suggestions or references for future tests and researches.

* See Section 3.06 for detailed interpretation.

** See Section 1 for the definition of Type *B* SSO.

SECTION 1: INTRODUCTION

Wastewater collection and treatment systems are major capital investments in the infrastructure of municipalities across the nation. The proper performance of these systems is vital to enabling citizens and those conducting business in the municipalities to go about their daily lives. These systems do malfunction. When that happens, it can pose significant risks to public health and the environment, and thus adversely impact the overall quality of life. A major form of system malfunction is sanitary sewer overflows (SSOs). A SSO is defined as the discharge of untreated or partially treated wastewater from a separate sanitary sewer system.

The US Environmental Protection Agency (EPA) is in the process of developing a national policy addressing National Pollutant Discharge Elimination System (NPDES) requirements for sanitary sewer collection systems and SSOs. The need for a national policy has prompted the need to increase the level of our understanding of SSOs; their causes, their effects, and their relationships with other observable measurements such as weather, population change, level of maintenance activities, etc.

Recent discussions by experts pointed out that it is probably most beneficial to consider SSOs in several different types. For example, in the draft of Sanitary Sewer Overflow and Sanitary Sewer Operation, Maintenance, and Management Unified Paper, Avoidable SSOs and Unavoidable SSOs were defined. Others talked about wet weather and dry weather SSOs. Although not completely equivalent, both definitions are largely similar in the sense that dry weather SSOs are likely avoidable under sufficient maintenance activities, and an intense storm might overwhelm a sewer system regardless the level of maintenance activities.

Let us consider the following assumption:

If:

1. a sewer system had unlimited capacity (unlimited sewer pipe size, unlimited treatment capacity, and unlimited backup capacity), and
2. the system was maintained with unlimited manpower and financial resources,

then there would have been no SSOs.

If we accept this (reasonable) assumption, then it is clear that every SSO can be attributed to a lack of either system capacity, or system maintenance, or both. For the ease of writing in this report, let us refer to the two components as Capacity related and Maintenance related, respectively.

The Capacity related SSO problems are traditionally studied by engineers via simulation models. For example, the Sanitary Sewer Overflow Cost/Benefit Analysis recently conducted by Eastern Research Group, Inc, and Metcalf & Eddy, for the US EPA depended heavily on a computer simulation model. Generally, it is believed that the computer models capture well the state of a sewer system, in the Capacity related dimension.

There is an orthogonal dimension to the system capacity in SSO problems; i.e., and the maintenance activities. Although it is well understood that a sewer system maintenance program is very important, few have been able to quantify its impact on the system performance. Some even had difficulty in establishing any usefulness of maintenance programs in their analysis (Stalnaker and Rigsby 1997). Such difficulties seem to have been caused by, among other things, the severe lack of quality and sizable data on SSOs by municipalities.

As an exception, the CMU has kept good SSO records for approximately 15 years. They have also kept daily work records by maintenance crews for at least as many years. This database provided an opportunity to explore the relationship between sewer performance and maintenance types and maintenance intensity. The main objective of this study is to attempt to establish and to quantify such a relationship.

As we model the SSOs in the database provided by CMU, the first question to be clarified is how to characterize these types of SSOs.

We considered the definition of Avoidable SSOs, but thought it inadequate. An avoidable SSO should be one that can be avoided by some form of human activities. As evidenced by the study results (appearing later in this report), the SSOs recorded in the CMU data were not completely so.

We also considered the definition of Dry-weather SSOs, but thought it inadequate still. After all, many of the SSOs in CMU database were triggered by some rain but not overwhelming storms. The original definition of Dry-weather SSOs may have been prompted by the fact that SSOs were experienced more frequently in the winters, usually the drier seasons. In the Piedmont region of North Carolina, the winter weathers are quite wet, and SSO frequency is still higher in the winters.

The term of Maintenance-Related SSOs is very close to Avoidable SSOs, can not be used to describe the SSOs in question for the same reason why Avoidable SSOs was inadequate.

Overall, it is appropriate to define two types of SSOs, for the purpose of this study, as follows.

- **Type *A* SSO** -- Type *A* SSO is an SSO that occurs because of the lack of capacity at the treatment plants - its wastewater treatment capacity, its back-up capacity, etc. Type *A* SSOs usually occurs at or very near a treatment plant.
- **Type *B* SSO** -- Type *B* SSO is an SSO that is not a type *A* SSO.

With the above definitions, we can comfortably claim that the model to be developed in this study is for the frequency of the type *B* SSOs.

SECTION 2: DESCRIPTION OF DATA

Charlotte-Mecklenburg County is located in the Piedmont region of North Carolina. Low-lying rounded hills and gentle rolling ridges characterize the landscape. The local climate is both moderate and seasonal. Rainfall during the summer months can be characterized as high intensity and short duration, while during the winter months it is of lower intensity and longer duration.

As of July 1, 1998, Mecklenburg County had a population of 613,310 (Estimated by U.S. Bureau of the Census). This represents an approximately 20% increase during the last 8 years. From 1980 to 1990, the population in Mecklenburg County had a 26.5% increase.

The Charlotte-Mecklenburg Utility Department (CMU) has a wastewater collection system consisting of approximately 2,659 miles of separate sanitary sewers, 5 wastewater treatment plants and 55 pump stations and lift stations.

CMU's computerized Complaint History And Maintenance Processing System (CHAMPS) was designed and implemented in 1979 in order to effectively plan and control the activities associated with managing the sewer system. The system was designed to capture historical data relative to the installation, maintenance, inspection, and repair of sewer lines. This data provides the core information for the current study.

In particular, CHAMPS provides the following useful information for this study.

1. SSO records: time and location of each reported SSO (SSO Data).
2. Work records: repair and maintenance activities (Activity Data).

In addition to the above-mentioned key data, there are available the following supporting data:

1. Rainfall data (1983 - 1997) acquired from National Climatic Data Center for the Mecklenburg County area.
2. Groundwater elevation data (1984 - 1997) acquired from the

United States Geological Survey.
3. The data on the age of the systems.
4. Daily flow to the treatment plants (1984 - 1997).
5. Length of sewer (in miles) maintained by CMU over the years.

2.01 SSO Data.

The CHAMPS database contains 47 fields. These fields can be found in a copy of the CHAMPS manual attached in Appendix A. Each observation in the CHAMPS data is a reported SSO with its reporting time and SSO location. There are three main variables generated from this database. They are **TIME** (when an SSO occurred) **TOPO** (where an SSO occurred) and **SSO** (SSO frequency aggregated by **TIME** and **TOPO**) respectively.

2.02 Repair and Maintenance Activity Data.

The repair and maintenance data were provided in the tabular form by CMU as shown in Appendix B. There are 25 attributes in this database, that is, fiscal year and other 24 operations codes, with the measures of activity aggregated by fiscal year from 1980 to 1998.

The 24 operations codes are defined in the CHAMPS manual attached in Appendix A. Among the 24 codes, the following are considered as pro-active maintenance activities, and relevant to the current study.

1. CHAMPS Code 08 - Rapid Response (coded as X08 for analysis purpose). The unit of this measure is one location.
2. CHAMPS Code 09 - Jets & Combination Machines, or Combination Machines (coded as X09). The unit of this measure is one linear foot.
3. CHAMPS Code 10 - Rodder (coded as X10). The unit of this measure is one linear foot.
4. CHAMPS Code 11 - Off Street Cleaning (coded as X11). The unit of this measure is one linear foot.
5. CHAMPS Code 12 - Right-of-Way Mowing (coded as X13). The unit of this measure is one linear foot.
6. CHAMPS Code 14 - T.V. Inspection (coded as X14). The unit of this measure is one linear foot.

7. CHAMPS Code 15 - Herbicide (coded as X15). The unit of this measure is one linear foot.
8. CHAMPS Code 16 - Cleaning/Inspection of Manhole (coded as X16). The unit of this measure is one location.
9. CHAMPS Code 17 - Inspections (coded as X17). The unit of this measure is one location.

2.03 Rainfall Data

Daily total rainfall from a location in the Charlotte-Douglass International Airport (**RAIN**) from Jan. 1983 to Nov. 30, 1997.

2.04 Groundwater Level

Groundwater elevations were acquired from the United States Geological Survey. Monitoring data was obtained from three wells around the Charlotte-Mecklenburg area. One of the wells is in the Hornets Nest Park, one is by Highway 521 near South Carolina and one is on Ridge Road in the northern part of the county. For the purpose of the analysis, the groundwater level (GW) is the mean number of feet below surface. A higher value of GW implies a lower groundwater level.

2.05 System Age

Sections of the sewer system under CMU's jurisdiction were coded with their dates of installation. Therefore, each reported SSO is associated with an age of the sewer section. For analysis purpose, the system age (**AGE**) is coded A (Past-1960), B (1961-1971), C (1972-1984) and D (1985-Present).

This information was supplied by CDM (CDM, 1994, pp.1-6 through 1-8). It is based on as-built drawings, the recorded date of construction, and the corresponding county topographical map (Figure1).

2.06 Daily flow to Treatment Plants

The daily flow data, in million gallons, were obtained from all the regional treatment plants and aggregated into monthly data. The total monthly flow data are coded as **FLOW**.

2.07 Sewer System Length

Total sewer system length (SSL) in miles maintained by CMU over the years is as follows.

Year	SSL
1971	946
1972	1045
1973	1100
1974	1207
1975	1283
1976	1390
1977	1447
1978	1475
1979	1530
1980	1585
1981	1640
1982	1670
1983	1700
1984	1730
1985	1767
1986	1882
1987	1913
1988	1992
1989	2123
1990	2205
1991	2271
1992	2303
1993	2362
1994	2426
1995	2482
1996	2565
1997	2659
1998	2764

The above database forms the basic information background for the current study.

SECTION 3: MODEL DEVELOPMENT

SSOs are caused by a combined effect of a large set of interactive factors. Understanding SSOs and their relationship to sewer systems is a complex undertaking. The objective of this study is to capture and quantify a relationship between reported type *B* SSOs and observed levels of some major factors via statistical modeling. In particular, we hope to capture and quantify statistically the impact of sewer system maintenance activities on SSOs, in terms of maintenance intensity and maintenance type.

It is to be mentioned here that any mathematical model is, at its best, an approximation to the true state of the nature. Study results, as consequences of a modeling process, should not be taken as final conclusions, but as reference, information to be used in future studies on similar topics. Particularly in this study, the data was not collected from a carefully designed setting. Although scientific techniques can help to reduce much of the difficulties caused by non-designed survey data, the study remains exploratory in nature.

With this in mind, let us proceed to develop the study model.

3.01 Dependent Variable and Associated Model

Sewer system performances can be gauged by a variety of indicators. Among them, SSOs are probably the most accepted and widely used indicators and are the chosen indicators for system performance in this study. Since SSOs occur in a discrete manner in time and CMU records only report the occurrences and not the amount of SSO, it is natural to study the frequencies via a Poisson Regression Model.

The first step in the study is to aggregate the data in time. Data aggregation is an approximation process. This can be done in different ways according to study objectives. Since we are primarily interested in the macroscopical patterns of SSOs, and since we have more than 14 years of data collected, it is quite reasonable to aggregate the SSO occurrences by month.

We denote the SSO frequency in a given month as Y. It is reasonable to assume that Y is a Poisson random variable with an intensity parameter λ. The monthly SSO frequencies from 1982 to 1997 provided by CMU are independent observations of this random variable. These observations are not identically distributed. The intensity parameter, λ, as a part of the model, is assumed to be a function of many other factors.

Suppose the factors of interest can be measured by variables, X_1, X_2, ... X_k with regard to the SSO frequencies. We assume that the relationship between SSO frequency, Y, and the independent variables, X_1, X_2, ... X_k can be described by the following linear function.

(1) $$\log(\lambda)=\mu+\beta_1X_1+\cdots+\beta_kX_k$$

where $\beta_1, \cdots, \beta_k$ are regression parameters.

3.02 Independent Variables

Before an attempt is made to identify the independent variables, we will revisit the primary question of interest: What causes SSOs? Unfortunately, there are probably no simple or clear-cut answers to the question. For the purpose of this exploratory study, let us adopt a Load-Capacity perspective of sewer system performances, specifically with respect to SSOs.

The Load-Capacity perspective is a simplified filter through which independent variables are selected and interpreted. With this perspective, it is assumed that all SSO factors can be classified into two basic categories. They are load related (Load) and capacity related (Capacity), respectively. In general, it is reasonable to conceptualize the sewer systems as wastewater conveyance systems operating at a capacity level. If the systems are overloaded and its capacity limit is exceeded, then SSOs will occur. Even for a same system, the system capacity is not a constant. It varies according to weather, seasons and many other conditions. For an example, sewer system maintenance is clearly a factor that will affect the conditions and the capacity of the systems. At least, we hope that this study will help to establish the effect of maintenance activities on the system capacity.

In selecting the independent variables, let us first consider rainfall, universally considered one of the most important impacting SSOs. We argue that rainfall should be a secondary independent variable provided the flow volume to the treatment plants is used as an independent variable. There are two steps in our argument for that view.

1. The impact of rainfall on sewer systems is delivered through inflow and infiltration. The process of rainfall becoming inflow and infiltration is a complex one, and not well understood. In gauging the impact of rainfall on the sewer systems, one may bypass the inflow and infiltration process and measure directly the flow to the treatment plants. After all, the impact level of the rainfall is only determined by the amount of rainfall that actually gets into the systems. Of course, flow to the treatment plants not only contains inflow and infiltration by rainfall, but also all other sources of flow. Does that matter? We answer this question in the next step.

2. The main objective of this study is to capture the relationship between sewer system maintenance activities and the sewer system performances. This objective is achieved by examining how much difference maintenance activities can make in system capacity (or system condition), when the system load is controlled. In view of the Load-Capacity perspective defined above, it is sufficient to describe the comprehensive load on the systems, but not necessary to separate the different sources of the load. In other words, as long as the model describes the system load at every point in time, there is no need to specifically describe the proportion of system load induced by rainfall.

After the flow to the treatment plants is adopted as a primary explanatory variable, the amount of rainfall will be numerically gauged in the model as a secondary independent variable. The result will further support the above argument.

Remark: *Although this study does not specifically require a clear mechanism to describe the proportion of inflow and infiltration induced by rainfall, the problem itself is of great importance. The* *industry-standard simulation models for measuring sewer system capacity depends heavily on the value of rain induced inflow and infiltration ratio (I/I ratio). A small difference in the estimated value could lead to a significant difference in the outcomes of the simulation. The estimation problem of I/I ratio deserves a serious separate study.*

Next, let us consider the flow to the treatment plants. Again from the Load-Capacity perspective, many factors could be contributing to the load of the sewer system, but ultimately the combined effect is manifested in the form of the total volume of the wastewater received at the treatment plants. From this viewpoint, the total flow to the treatment plants is naturally an index that will be used in the model to describe the system load.

With regard to groundwater levels, which is also commonly considered as a source of inflow and infiltration, an identical argument to the rainfall can be applied. That is, the portion of groundwater that finds its way into the sewer systems is also included in the total flow to the treatment plants. In fact, a visual inspection of Figure 2 (average monthly flow index versus an adjusted average monthly groundwater level) reveals that the groundwater level is somewhat indicated by the flow to the treatment plants. (Higher value of **WELL** means lower groundwater level.) The correlation coefficient is -0.65. Groundwater level is also considered as a secondary independent variable to be gauged at a later stage of the modeling process.

3.03 Analysis - Stage 1: FLOW

Let us make an attempt to establish a model relationship between SSO frequencies and the flow to the treatment plants, the primary independent variable with regard to system load. First we aggregate both SSO and flow data monthly.

To capture the relationship between SSO and the flow, it is necessary to determine a stable frame of reference in time. The sewer system under CMU's jurisdiction has been expanding continuously in time over the last several decades. We first identify a particular region of the systems which was in place before 1984 and call it "the stable region". This region includes areas with **AGE** values A, B, and C. The dependent variable is defined as

Y = the total monthly SSO frequency in the stable region.

Likewise, adjustments must be made to the total monthly flow to the treatment plants to account for the continuous expansion of the sewer systems in time. An index for the system load is defined to be the total monthly flow to the treatment plants divided by the average length of the system, i.e.,

FLOW = (Total Monthly Flow in MG) / (Sewer Length in Miles),

where MG is millions of Gallons.

Let us consider first the model

(2) $$\log(\lambda)=\mu+\beta\,\mathbf{FLOW}.$$

Using the GENMOD Procedure of SAS version 6.12, (see Appendix C for SAS output,) we have 170 observations,

1. μ is estimated to be 2.2584, the standard error is estimated to be 0.1127 and the p-value of the test statistic for the hypothesis of $\mu=0$ is less or equal to 0.0001.
2. β is estimated to be 0.8789, with an estimated standard error of 0.1285, and the p-value of the test statistic for the hypothesis of $\beta=0$ is less or equal to 0.0001.

This indicates that there is strong evidence suggesting that the SSO frequency, as defined above, is positively related to the flow index. A higher level of the flow index, **FLOW**, leads to a higher probability of an SSO, or a higher average of a monthly SSO frequency.

At this point, we introduce an intuitive way of interpreting a statistic associated with the Poisson regression methodology. The statistic is Deviance. Deviance is a special statistical distance measuring how much of the fluctuation of SSO frequency in time is explained by the model employed here.

It is often useful to keep in mind that if a model could explain completely why SSO frequency fluctuates in time, then we would have had the complete knowledge of what were the factors of SSO, qualitatively and quantitatively. In reality, we do not have that kind of knowledge and, we rely on statistical distances such as Deviance to tell us how much of the total variation (or deviance) is explained by a specific factor (or independent variable).

In the current study, the total deviance is 803.92. This is the deviance after the constant μ is fitted. The deviance, after **FLOW** is fitted, is 730.13. The difference, 73.79 or 9.2% of the total deviance, is explained by the linear term **FLOW** in the model. The most important statistic here is the percent 9.2%. This value projects how much fluctuation in SSO that can be attributed to the change in the flow index.

3.04 Analysis - Stage 2: Seasons

Next, we consider the seasonal effect on the SSO frequency after the flow index is included. It is to be pointed out that the seasonal effect considered here is a Capacity effect, not a Load effect. Seasonal trend is very clear in the SSO frequency plot in Figure 3. This trend is caused by a combination of two separate trends: one is the seasonal trend of flow into the system by varying natural and human behaviors, and the other is caused by the change in the condition of the system in conveying wastewater. Again, we consider the seasonal effect in the framework of the Load and Capacity perspective discussed above.

The seasonal trend of flow into the system has already been captured by the flow index, as clearly shown in Figure 3. By adding a seasonal factor after **FLOW** is fitted, the new factor is expected to capture only the seasonal fluctuation in the condition (or the capacity) of the sewer systems.

The seasonal factor is introduced into the model by categorical variables $\mathbf{M}_k$, k=1,2, ..., 12. For example, M_1 is for the month of January. $\{M_1=1\}$ means that the month is January, and $\{M_1=0\}$

means that the month is not January. The index k is for the k^{th} month of a year, i.e., 1 (January), 2 (February), 3 (March), 4 (April), 5 (May), 6 (June), 7 (July), 8 (August), 9 (September), 10 (October), 11 (November) and 12 (December).

The model at this stage is

(3) $$\log(\lambda)=\mu+\beta\,\mathbf{FLOW}+\Sigma_{k=1\text{ to }11}\,\beta_k\,\mathbf{M}_k.$$

There are only 11 terms for the season in the above model. This is so because the month of December is indicated by $\mathbf{M}_k$=0, k=1, 2, ..., 11. These 11 terms form one group of variables to gauge seasonal change in sewer system condition.

The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

1. μ is estimated to be 2.7535, the standard error is estimated to be 0.1949 and the p-value of the test statistic for the hypothesis of μ=0 is less or equal to 0.0001.
2. β is estimated to be 0.5554, with an estimated standard error of 0.1915, and the p-value of the test statistic for the hypothesis of β=0 is equal to 0.0037.
3. The estimated values for the parameters β_1 through β_{12} are as tabulated in the following table.

Parameter	Estimate	p-value < or =
β_1	0.0919	0.4984
β_2	0.0114	0.9344
β_3	-0.0039	0.9776
β_4	-0.1964	0.1801
β_5	-0.2805	0.0605
β_6	-0.4457	0.0052
β_7	-0.5861	0.0003
β_8	-0.6563	0.0001
β_9	-0.5614	0.0008
β_{10}	-0.2856	0.0599
β_{11}	-0.0819	0.5671

β_{12}	0.0000	NA

One may interpret these estimates as follows. Using β_{12} as a level of reference, in January, February, March, April and November, the conditions of the sewer systems are not very different from that of December. From May to October, the system condition (or capacity) is significantly better, and the likelihood of SSO decreases as manifested by the negative values of the estimates.

The monthly average of SSO frequencies from 1983 to 1997 is graphed in Figure 4. The above table is also graphed in Figure 4. As seen in the comparison, the observed seasonal trend is largely captured by the estimates of the parameters.

In terms of the deviance explained by the current model, **FLOW** still explains 73.8 in the total deviance (803.9), or 9.2%; the group of season variables, M_1, ..., M_{12}, explains an additional 193.58 in the total deviance, or 24.1%.

3.05 Analysis - Stage 3: General Maintenance

At this point, a cumulative 33.3% of the total deviance has been described by the model employed. Conversely, the remaining 66.7% of the total deviance is not explained. In Stage 1, we started with 100% of the total deviance, and we then used one factor, flow index, to describe the system load, and a second factor, season index, to describe the seasonal change of system capacity. Now we face 66.7% of the total deviance. What other factors are important in explaining the remainder?

With regard to the performance of the sewer systems, one may view maintenance activities as means of improving the system capacity. It is natural to gauge the model relationship with maintenance activities. To do so, we must develop reasonable index measures for comprehensive maintenance intensity.

In the data provided by CMU, we have identified 9 different specific operation codes (see Data Description) that are considered pro-active with regard to controlling SSO. These data are aggregated yearly.

Since the sewer systems under CMU jurisdiction have expanded continuously over the years, the comprehensive activity data kept by CMU must be adjusted for the fixed region of reference, the stable region since 1984. After some considerable consultation, we decided that all the yearly maintenance data should be converted to measures per unit (per linear mile of sewer). Furthermore, the adjusted maintenance measures are all normalized to account for their vastly different scales and variations over the years.

Before the adjustments, it is to be pointed out that there are three types of maintenance operations, CHAMPS Codes 9, 10, and 14, that are not completely pro-active. Code 9 (X09) is the footage of sewer cleaned by Jets & Combination Machines. Code 10 (X10) is the footage of sewer cleaned by Rodder. Code 14 (X14) is footage of sewer inspected with TV cameras. These activities, in addition to the regularly scheduled maintenance, are ordered to respond to each reported SSO. According to CMU, on the average, each reported SSO requires a section of sewer of length 250 feet to be cleaned and inspected. To take this passive portion of the maintenance, caused directly by SSOs, out of the maintenance intensity measures, we define, for each year,

1. X09s = X09 - 250 • (Total yearly number of SSOs),
2. X10s = X10 - 250 • (Total yearly number of SSOs),
3. X14s = X14 - 250 • (Total yearly number of SSOs).

Next, for each year, let

1. X08* = X08 / (Total system length in miles),
2. X09* = X09s / (Total system length in miles),
3. X10* = X10s / (Total system length in miles),
4. X11* = X11 / (Total system length in miles),
5. X12* = X12 / (Total system length in miles),
6. X14* = X14s / (Total system length in miles),
7. X15* = X15 / (Total system length in miles),
8. X16* = X16 / (Total system length in miles),
9. X17* = X17 / (Total system length in miles).

Finally, we standardize these variables.

1. Z08 = [X08* - (the mean of X08*)] / (the standard deviation of X08*),
2. Z09s = [X09* - (the mean of X09*)] / (the standard deviation of X09*),
3. Z10s = [X10* - (the mean of X10*)] / (the standard deviation of X10*),
4. Z11 = [X11* - (the mean of X11*)] / (the standard deviation of X11*),
5. Z12 = [X12* - (the mean of X12*)] / (the standard deviation of X12*),
6. Z14s = [X14* - (the mean of X14*)] / (the standard deviation of X14*),
7. Z15 = [X15* - (the mean of X15*)] / (the standard deviation of X15*),
8. Z16 = [X16* - (the mean of X16*)] / (the standard deviation of X16*),
9. Z17 = [X17* - (the mean of X17*)] / (the standard deviation of X17*).

To describe the general intensity level of CMU's pro-active sewer maintenance, the most natural statistic to use is probably the average of the above 9 individual indices, which will be denoted by **Z**.

Z = (Z08 + Z09s + Z10s + Z11 + Z12 + Z14 + Z15 + Z16 + Z17)/9.

Can this general pro-active maintenance index explain some of the remaining deviance from Stage 2?

The model at this stage is

(4) $$\log(\lambda)=\mu+\beta\,\mathbf{FLOW}+\Sigma_{k=1\text{ to }11}\,\beta_k\,\mathbf{M}_k+\alpha\,\mathbf{Z}.$$

The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations. **Z** is represented in the output as **ZMEAN**.

The estimated values for the parameters are as tabulated in the following table.

Parameter	Estimate	p-value < or =
μ	2.8952	0.0001
β	0.3765	0.0227
β_1	0.0807	0.4942
β_2	-0.0092	0.9394
β_3	-0.0074	0.9513
β_4	-0.2185	0.0870
β_5	-0.2954	0.0232
β_6	-0.4793	0.0006
β_7	-0.6060	0.0001
β_8	-0.6739	0.0001
β_9	-0.5819	0.0001
β_{10}	-0.2995	0.0235
β_{11}	-0.0866	0.4872
β_{12}	0.0000	NA
α	-0.4268	0.0001

First we notice that the estimated α is -0.4268 with strong statistical evidence (p-value is less or equal to 0.0001) that the true value of α is negative. **That means that higher level of Z, the pro-active maintenance index, leads to lower level of λ, and in turn a down shift of the probability distribution of SSO frequency.**

The deviance, explained by this variable, is 131.99 or 16.42% of the total deviance (803.9205).

Cumulatively the model can explain 49.68% the total deviance at this point.

3.06 Analysis - Stage 3*: Individual Maintenance Types

At this stage, we will examine the impact of each individual type of maintenance activity, as reflected by the model.

It is very important to keep in mind, as we run through the individual types of activities, that each type is embedded in a comprehensive maintenance program. Any relationship established in this section of the analysis should be interpreted in conjunction with the comprehensive nature of the overall maintenance. It is hoped that the interpretations provided here will be taken as preliminary suggestions.

The base model used here is

$$(5) \qquad \log(\lambda)=\mu+\beta\, \mathbf{FLOW}+\Sigma_{k=1 \text{ to } 11}\, \beta_k\, \mathbf{M}_k.$$

The justification for that is that this model covers the system load change and the system capacity change because of the seasons. With these two major factors under consideration, it is reasonable to ask whether or how much each individual type of maintenance activity can help to explain the fluctuation of SSO frequency.

To do that, we use the following model.

$$(6) \qquad \log(\lambda)=\mu+\beta\, \mathbf{FLOW}+\Sigma_{k=1 \text{ to } 11}\, \beta_k\, \mathbf{M}_k+\alpha_i\, \mathbf{Z}_i$$

With **Zi**, i =1, 2, ..., 9, being any one of the nine individual maintenance intensity indices, we will estimate α_i and gauge its statistical significance.

Rapid Response. A rapid response crew carries out a work order immediately after a sewer related problem is reported. This type of activity is coded as Z08. Let Z08 be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is -0.3188 with a p-value less or equal to 0.0001 in testing the hypothesis that $\alpha=0$. This implies that, with high statistical confidence, rapid responses tend to reduce SSO frequency. In consultation with CMU operators, they suggested that this relationship may be attributed to the ability of averting a potential SSO before it actually occurs.

This variable, Z08, explains an additional 242.5 (30.16%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 509.78, or 63.42%.

Jets & Combination Machines. Jets & Combination Machines stands for machines used in cleaning procedures with high-pressure water and debris vacuuming capability. This type of activity is coded as Z09s. Let Z09s be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is 0.0851 with a p-value 0.0095 in testing the hypothesis that α_i=0. At a first glance, this may seem to imply that, with a positive estimate for α_i, such cleaning procedure may lead to a higher SSO frequency, although slightly. We are reminded of the existence of the comprehensive maintenance program. A positive estimate here only suggests that such procedure is not as effective as some other cleaning procedures. More usage of Jets & Combination Machines may be taking away resources from other more effective maintenance activities. It still does not mean that this procedure can be replaced by a more effective one. It simply suggests that the spectrum of situations, when such procedure was called for, as in CMU's current practice, might have been wider than it should be. In fact, according to CMU operators, CMU has already started to shift to a more effective procedure.

This variable, Z09s, explains only an additional 21.36 (2.66%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 288.73, or 35.92%.

Rodder. Rodder (Root Removal) is a machine with a root-removing device used in cleaning procedures. This type of activity is coded as Z10s. Let Z10s be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is -0.2211 with a p-value less or equal to 0.0001 in testing the hypothesis that α_i=0. The negative value of the estimate implies such cleaning procedure tends to lead to lower SSO frequency. By a comparison with Jets & Combination Machines, this procedure seemed much more effective, at least from a modeler's point of view.

This variable, Z10s, explains an additional 132.01 (16.42%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 399.38, or 49.68%.

Off-Street. Off-Street Cleaning stands for a labor-intensive procedure in which maintenance workers manually clean and remove roots or debris in hard-to-reach areas where the use of other machinery is not practical. This type of activity is coded as Z11. Let Z11 be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is -0.1710 with a p-value less or equal to 0.0001 in testing the hypothesis that α_i=0. The negative value of the estimate implies such cleaning procedure tends to lead to lower SSO frequency.

This variable, Z11, explains an additional 84.60 (10.52%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 351.97, or 43.78%.

Right-of-Way Mowing. Right-of-Way Mowing is an activity to clear or maintain access paths to sewer lines by the creeks. This type of activity is coded as Z13. Let Z13 be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is -0.1633 with a p-value less or equal to 0.0001 in testing the hypothesis that α_i=0. The negative value of the estimate implies such procedure tends to lower SSO frequency.

This variable, Z13, explains an additional 97.95 (12.18%) in the deviance remainder from the base model (5). This brings the total deviance explained by the model up to 365.32, or 45.44%.

T.V. T.V stands for the use of television camera in inspecting the sewer pipes. This type of activity is coded as Z14s. Let Z14s be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is -0.0354 with a p-value 0.3106 in testing the hypothesis that α_i=0. The large p-value indicates that there is no sufficient evidence to suggest that the true value of α_i is non-zero. This procedure does not seem to have a very significant impact on SSO frequency.

This variable, Z14s, explains only an additional 3.54 (0.44%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 270.91, or 33.70%.

Herbicide. Herbicide stands for the application of herbicide to control root growth in sewer pipes. This type of activity is coded as Z15. Let Z15 be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 160 observations (due to some missing values of the Herbicide data).

The estimated α_i is -0.2296 with a p-value less or equal to 0.0001 in testing the hypothesis that α_i=0. The negative value of the estimate implies such procedure tends to lead to lower SSO frequency.

With only 160 observations available, the total deviance in the sample is also changed to 782.4079. This variable, Z15, explains an additional 92.89 (11.78%) in the remainder deviance from the base model (5), which is 527.36. (See Appendix C.) This brings the total deviance explained by the model up to 347.93, or 44.47%.

Manhole Inspection and Cleaning. Manhole Inspection and Cleaning is largely an alternative when a weather condition prevents other regular maintenance activities to be carried out in any meaningful way. This type of activity is coded as Z16. Let Z16 be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

The estimated α_i is 0.0875 with a p-value 0.0057 in testing the hypothesis that α_i=0. The positive value of the estimate implies that such activities tend to lead to higher SSO frequency. Why should inspection and cleaning of manhole do any harm to the sewer maintenance? They do not. This, in fact, is an excellent example to illustrate that the relationships established in this section must be interpreted in conjunction with the other maintenance activities. This particular activity is known to be inefficient in the sense that it wastes resources, which may otherwise be used to achieve greater good for system maintenance.

This variable, Z16, explains on an additional 24.69 (3.07%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 292.06, or 36.33%.

Inspection. This inspection stands for regular scheduled sewer system inspection. This type of activity is coded as Z17. Let Z17 be the Z_i in (6). The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 160 observations, again due to some missing values in inspection data.

The estimated α_i is -0.2872 with a p-value less or equal to 0.0001 in testing the hypothesis that α_i=0. The negative value of the estimate implies such cleaning procedure tends to lead to lower SSO frequency.

This variable, Z17, explains an additional 164.41 (20.41%) in the remainder deviance from the base model (5). This brings the total deviance explained by the model up to 431.45, or 53.67%.

Relative Ranking. The above analysis suggests that, these individual maintenance activities may be relatively ranked according to their ability in explaining the deviance remainder from the base model (5). Consider a empirical score for relative strength, RS, defined as follows.

(7) RS = – (Sign of Estimated α_i) • (Proportion of Deviance by Zi).

In a decreasing order, we have the following ranking.

TYPE	RS
Rapid Response (Z08)	30.16%
Inspection (Z17)	20.41%
Rodder (Z10s)	16.42%

Right-of-Way Mowing (Z13)	12.18%
Herbicide (Z15)	11.78%
Off-Street (Z11)	10.58%
T.V. (Z14s)	0.44%
Jets & Combination Machines (Z09s)	-2.66%
Manhole Inspection and Cleaning (Z16)	-3.07%

Remarks.

The ordering of the maintenance activity types here should not be taken as a rank of importance of these activities out of context. Each Relative Strength is calculated for a particular activity without others being considered in the model. Since all types of maintenance activities are used concomitantly, it is probably best to interpret such ordering in the following fashion.

Sewer system maintenance is a complex task. The resources for maintenance are often limited. There is usually a large variety of maintenance situations that may call for different procedures. It would not be reasonable to claim one particular procedure is better than another is in general. Rather the mixture of different maintenance procedures in an existing program can be viewed, by either design or tradition or convenience, as a means to utilize the combined effect of these component procedures.

If one accepts the above viewpoint, then one cannot help to ask what the optimal (or most efficient) mixture of the component activities may be to control SSO frequency. The answer to such question is unknown, and not easy to obtain. The ordering provided in the above table may be interpreted nicely in this context. Given the current (or the last 14 years' average) mixture of the component maintenance procedures at CMU, the table suggests that the overall effect may be improved if the activities with higher RS scores are increased and those with lower scores, particularly the negative ones, are decreased.

In summary, the RS scores are meaningful only with respect to the current state of the mixture of maintenance activities in a particular program.

3.07 Analysis - Stage 4: Maintenance Management

Having provided a ranking for the various types of the maintenance activities, let us return to Stage 3 where the model considered is

(8) $$\log(\lambda)=\mu+\beta\,\mathbf{FLOW}+\Sigma_{k=1\text{ to }11}\,\beta_k\,\mathbf{M}_k+\alpha\,\mathbf{Z}.$$

According to CMU, the management style of the maintenance program for its sewer system has three clearly different phases during the last 14 years. Before 1990, there was a regular maintenance schedule, developed according to Schaaf's suggestion and CHAMPS data. Although the schedule algorithm was not computerized then, the actual execution of the schedule was believed to be reasonably close to what was intended. In 1990, there was a management change, and therefore, the philosophy of regular sewer maintenance was changed. Between 1990 and 1994, the regular maintenance was largely carried out by means of cleaning a whole neighborhood or subdivision, when there was a reported sewer problem near by. Most maintenance orders were issued based on subjective judgment and convenience. The argument for such a method is twofold. One is that a reported problem is usually an indication that this particular area needs maintenance. The other is that it is cost-efficient to clean the area with a reported problem while a crew is already in the area. This philosophy provides a contrast to the Schaaf's methodology, in the sense that Schaaf's methodology relies on a balance between reported current problems and cleaning history. The philosophy adopted by CMU between 1990 and 1994 weighted much on the reported current problems. Did they weight it too high? We will attempt to answer that question at this stage. It is to be mentioned first that, from 1995 on, CMU has again moved to carry out their regular maintenance based on Schaaf's methodology. In fact, this time around, the scheduling algorithm is computerized.

With the above information, it is reasonable to define an independent variable, say, **SCHAAF**, to distinguish the period from 1990 to 1994, from the other two periods. Let {**SCHAAF**=1} mean the time when Schaaf-based maintenance schedule was implemented, and let {Schaaf=0} stand for the time when Schaaf's method was not followed.

Based on (8); let us consider

(9) $\log(\lambda)=\mu+\beta$ **FLOW**$+\Sigma_{k=1 \text{ to } 11}\, \beta_k$ $\mathbf{M_k}$$+\alpha$ **Z**$+\delta$ **SCHAAF**,

where δ is the parameter corresponding to variable **SCHAAF**.

The SAS GENMOD Procedure showed the following key results, (see Appendix C for SAS output,) with 170 observations.

Parameter	Estimate	p-value
β	0.0369	0.8395*
α	-0.5447	0.0001
δ	-0.3188	0.0001

The negative estimate of δ suggests that, when Schaaf's methodology is used, the average frequency of SSO is decreased, if levels of all other factors are held constant.

(*) The p-value here, for the hypothesis that $\beta=0$, is 0.8395. This indicates that the newly included variable, **SCHAAF**, is somewhat correlated with the variable **FLOW**. It is beyond doubt that **FLOW** is a useful variable in influencing the frequency of SSOs. The Type 1 Analysis (see Appendix C) shows that if one adds **SCHAAF** in the model after the **FLOW**, the season and the general maintenance are already fitted, an additional deviance of 36.05 or approximately 4.48 % of the total deviance is explained. At this stage, our main goal is to examine whether **SCHAAF** increase the power of the model. We will go back to re-gauge variable **FLOW** at a later stage.

At this stage, the variables representing the flow index, the seasons, the general maintenance intensity, and the Schaaf's methodology, together explains 54.16% of the total deviance.

3.08 Analysis - Stage 5: Hugo

In 1989, Hurricane Hugo hit Charlotte-Mecklenburg area in late September. The system was overwhelmed by the storm, and its after-effect lingered for several months. Many of the SSOs are presumably Hugo related. To figure the Hugo effect in the model, we let {**HUGO**=1} stand for the year when the hurricane hit, and {**HUGO**=0} for other years. We consider model

(10) $\log(\lambda)=\mu+\beta\,\mathbf{FLOW}+\Sigma_{k=1\text{ to }11}\,\beta_k\,\mathbf{M_k}+\alpha\,\mathbf{Z}+\delta\,\mathbf{SCHAAF}+\theta\,\mathbf{HUGO}$,

where θ is the parameter corresponding to variable **HUGO**.

The SAS GENMOD Procedure showed the following key results, (see Appendix C for SAS output,) with 170 observations.

Parameter	Estimate	p-value
β	0.1477	0.4127**
α	-0.5015	0.0001
δ	-0.2468	0.0030
θ	0.3124	0.0003

The positive estimate of θ suggests that Hugo may have been the reason why SSO frequency surges in 1989.

(**) We notice that, with **HUGO** in the model, this p-value decreases considerably (as compared to the previous model in (9)). This suggests that **HUGO** may have explained some of the correlation between **FLOW** and **SCHAAF**.

At this stage, the variables representing the flow index, the seasons, the general maintenance intensity, the Schaaf's methodology, and Hugo together explains 57.55% of the total deviance.

3.09 Analysis - Stage 6: FLOW Revisited

Now let us go back and investigate variable **FLOW** a little further.

Thus far, **FLOW** has been classified as a Load variable. Since the flow to the treatment plants also has demonstrated seasonal trend over the years, the 9.2% of the total deviance attributed to **FLOW** (See Stage 1) may reflect some contribution from Capacity factors, for example, the seasons. Is **FLOW** really a Load variable? To answer this question, we expand the model to include a non-linear term in **FLOW**. The need of a non-linear term in **FLOW** is also suggested by the fact that at Stage 4, when we include variable, **SCHAAF**, the p-value for β not equal to zero is greatly inflated. This fact suggests that **SCHAAF** may be linearly related to **FLOW**, and an added non-linear term may help the calculation, the power and the validity of the model.

Let us consider

(8) $\log(\lambda) = \mu + f(\mathbf{FLOW}) + \Sigma_{k=1 \text{ to } 11} \beta_k \mathbf{M_k} + \alpha \mathbf{Z} + \delta \mathbf{SCHAAF} + \theta \mathbf{HUGO}$.

where $f(\mathbf{FLOW}) = a\ \mathbf{FLOW} + b\ \mathbf{FLOW}^2$, and a, b are parameters.

The SAS GENMOD Procedure showed the following key results, (see Appendix C for SAS output,) with 170 observations.

Parameter	Estimate	p-value
a	1.9856	0.0855
b	-0.9634	0.1069
α	-0.4984	0.0001
δ	-0.2229	0.0077
θ	0.2971	0.0006

The Type 1 and 3 Analysis (see Appendix C) shows that the non-linear expansion of the model with respect to **FLOW** is supported by the data. All the variables in the model at this stage, together, explain 430.74 in deviance or 58.29% of the total deviance.

3.10 Analysis - Stage 7: The Final Model

A 1998 study by American Society of Civil Engineers and Black & Veatch, LLP, for US EPA suggests in Section 1.4 that the sewer system aging process is indexed by the remaining value of the system, and such value decreases in time at a constant yearly rate. The basic point of reference adopted in that study is that, without any maintenance the system will deteriorate at a constant rate for about one hundred years. The role of sewer maintenance activities is then to slow or reverse the aging of the system.

To complete this study, it is necessary to, after all reasonable factors are considered, include Time as a final term to see if the amount of maintenance by CMU in the last 14 years has prevented the aging of the system. Let **T** be the yearly time from 1983 to 1997, we consider

$$(11) \quad \log(\lambda) = \mu + f(\mathbf{FLOW}) + \Sigma_{k=1 \text{ to } 11}\, \beta_k \mathbf{M_k} + \alpha\, \mathbf{Z} + \delta\, \mathbf{SCHAAF} + \theta\, \mathbf{HUGO} + \kappa\, \mathbf{T},$$

where f(**FLOW**)= a **FLOW** + b $\mathbf{FLOW}^2$, and a and b are parameters associated with **FLOW**, and κ is the unknown parameter describing the unit rate of decay corresponding to yearly time in SSO frequency.

The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

Parameter	Estimate	p-value
μ	-119.3656	0.0001
a	2.5839	0.0175
b	-1.4066	0.0133
$\beta 1$	0.1135	0.2648
$\beta 2$	-0.0200	0.8471
$\beta 3$	0.0312	0.7660
$\beta 4$	-0.2321	0.0343
$\beta 5$	-0.3067	0.0063
$\beta 6$	-0.5159	0.0001
$\beta 7$	-0.6359	0.0001
$\beta 8$	-0.6908	0.0001
$\beta 9$	-0.6213	0.0001
$\beta 10$	-0.3215	0.0045
$\beta 11$	-0.0883	0.4090
$\beta 12$	0.0000	.
α	-0.2324	0.0044
δ	-0.5280	0.0001
θ	0.3658	0.0001
κ	0.0611	0.0001

The positive value of the estimated κ suggests that the system is aging despite of the maintenance effort.

This model explains 64.05% of the total deviance.

SECTION 4: MODEL INTERPRETATION

If we had understood completely why and how SSOs occurred, then we would have had a model that would explain the fluctuation of SSO frequency perfectly for the last 14 years. In reality, we do not. We attempt to attribute the total fluctuation to some independent factors that we think are relevant. The proportion of the total deviance explained by a factor may be thought of as, how much the factor can be attributed to in the entire problem.

4.01 FLOW

FLOW explains 9.78% of the total deviance. Since **FLOW** is the first variable to be included in the model, one may say that the amount of fluctuation of SSO frequency due to **FLOW** is less or equal to 9.78%.

The estimated coefficients, a and b, for **FLOW** and $\mathbf{FLOW}^2$, are respective 2.5839 and -1.4066. If every other factor is fixed at a constant level, then the results of the analysis suggests that **FLOW** impacts SSO frequency via

$$f(\mathbf{FLOW}) = -1.4066\ \mathbf{FLOW}^2 + 2.5839\ \mathbf{FLOW}. \qquad (12)$$

The flow index has a range from 0.3531 to 1.4280. Over this range, f(**FLOW**) is graphed in Figure 5. This graph indicates that the impact of flow in the system may not be as simple as one may think. While it is clear that more flow is an indication of higher load, it is interesting to observe that as the flow increases over a threshold (0.9185) it may help to lower the likelihood of an SSO. This is an observation we did not anticipate. Upon further consideration, we conclude that this property may be interpreted as a self-cleansing property of the flow. As the flow reaches the threshold, its velocity may help to wash out debris and the like, and in turn makes it harder for blockages to form in the system.

4.02 Seasons

The seasonal effect is modeled by the 12 months of a year as a class variable. When the month of December is fixed as a point of reference, every other month is compared to it, and it leads to an additive term associated with each month as shown in Table 2. A graphical representation of these terms is plotted in Figure 6.

There are two elements in the seasonal effect. First, it causes a seasonal pattern in the flow to the treatment plants. Secondly, it causes the system capacity, or condition, to change. When **FLOW** was included in the model alone, the proportion of the deviance explained should already contain the flow fluctuation due to the seasons. When $\mathbf{M}_i$ (SSOMO in SAS output) is included in the model after **FLOW** is fitted, the proportion of the deviance explained by $\mathbf{M}_i$ could be reasonably attributed to system capacity change due to seasonal effect. This proportion is 24.82%, i.e., the seasonal fluctuation in sewer system capacity is responsible for nearly a quarter of the total fluctuation in SSO frequency.

4.03 Maintenance Activities

Although there are more than a few different types of maintenance activities we can consider, the complicated inter-relationship among them prevents us from including all of them individually together in the model. The index of general maintenance level, **Z** (ZMEAN in SAS output), serves as a good indicator for comprehensive maintenance. The term, Z, explains 17.16% of the total deviance. The impact of **Z** on SSO frequency is modeled via

(13) $$g(Z) = -0.2324\, Z.$$

A graphical representation of (13) is provided in Figure 7, over the range of **Z**, (-0.6612, 0.6355). It is clear in Figure 7 that higher level of maintenance leads to lower likelihood of SSO.

It may be interesting to note that the index for general maintenance explains nearly twice as much deviance as **FLOW** does, 17.16% versus 9.78%. **This comparison suggests how important the general maintenance is relative to the amount of flow in the system.** The deviance by the general maintenance (17.16%) is about 69.14% of the deviance by the seasons (24.82%). **This comparison also helps to gauge the significance of human maintenance activities versus that of nature, on an average.**

4.04 Schaaf's Methodology

Although there have been some studies done in the past regarding Schaaf's methodology in maintenance scheduling, we are not aware of any that evaluated the effect quantitatively in comparison with other major factors. The scheduling methodology used by CMU is a version of scheduling technique in Schaaf's spirit, but not as he had defined (see Schaaf ***). The scheduling method by CMU has also changed in time in the course of the last 14 years. We can still comfortably distinguish the periods when such schedules were followed. The variable (**SCHAAF**), after the **FLOW**, the seasons and the general maintenance level were fitted, explains 3.49% of the total deviance, a quantity smaller than anticipated, but strongly supported by the data.

4.05 Hugo

Natural disasters often blur our vision in seeking the truth. Hugo hit the Carolinas in the fall of 1989 and brought many months of unusual activities to the sewer systems in the Charlotte Mecklenburg area. When we distinguished that year from the others, the variable **HUGO** explains 3.05% of total deviance. This is also a model component strongly supported by the data.

4.06 Time

The variable, **T** (SSOYR in SAS output), is used to capture any remaining linear trend in SSO frequency in time. 5.75% of the total deviance is explained by **T**. This result suggests that the sewer system capacity, on the average, slightly worsened during the last fourteen years despite the maintenance effort by CMU. The coefficient of **T** is estimated to be 0.0611 with the link function being $\ln(\lambda)$. In terms of average number of SSO per year, this number translates to a 6.3% annual increase. This number may reflect an average rate of sewer system aging in this area. It is difficult to say how this rate is linked to the rate of decrease in remaining value of a section of the sewer system - a standard measure for system aging.

4.07 The Final Model

As we stated in the introduction, a model is, at its best, an approximation to the true relationship of SSO frequency and its factors. To prevent ourselves from drawing inferences on unfamiliar grounds, we confined ourselves to a set of important rules in the process of developing the model. The rules that we followed were as follows.

- **Agreement with common sense**. At each model development stage, the results must be in agreement with our common sense. This was achieved by attaching each result with at least one acceptable interpretation, in consultation with CMU maintenance operators and managers.
- **Type 1 analysis support**. Type 1 analysis is a step-wise analysis in Poisson regression. It is carried out by adding a new independent variable in the model after some other independent variables are fitted first. We consider a variable useful if the Type 1 analysis shows that a statistically significant portion of the deviance is explained by that variable. The list and the order of the independent variables are strategically designed to help us to understand the inter-relationships among the variables.
- **ML Estimate Support**. We consider a variable useful if the model parameters corresponding to this variable are estimated to be non-zero with well supported statistical significance. The estimates in the analysis are maximum likelihood estimates.

The percentage of the total deviance explained by the final model is **64.05%.** This number is a reflection of how much we understand the SSO problem. While 64.05% is a considerable part of the total deviance, there is still 35.95% of the deviance which we are not able to explain with scientific confidence. For this very reason, we do not envision our modeling process as an effort to provide a predictive tool, but as an effort to offer an exploratory technique to better understand the SSO and maintenance problems.

With the above study results, we are faced with a very important question: can we reasonably control SSO frequency? The answer, at the current level of maintenance, is unfortunately negative. To start with, there is a significant amount of variation in SSO frequency, 35.95% of the total deviance, unexplained by the model. Though we may be able to explain 64.05% of the total deviance, only two of the factors, the general maintenance activities and the Schaaf-like scheduling method, can be controlled. These two factors together explain only 20.65% of the total deviance, quite a distance away from being a dominating majority.

Can the level of flow, or the system load in general, be controlled? This may be an interesting question to be considered. As seen in this study, the flow explains less than 10% of the total deviance. We may conclude that, as far as Type *B* SSOs are concerned, the flow factor does not seem to be a top-ranked force in the grand picture of things.

The seasonal system capacity change, M_i, is the single most explanatory variable in the model. It seems that the system condition change by nature is at least as significant as that by all the human maintenance activities.

We offer three viewpoints to the results of this study We hope that these viewpoints may be proven worthy in future studies as well as future designs of maintenance programs. These viewpoints are:

1. It is possible that the current level of maintenance, as we have seen in this study, is far below the level that is necessary to make a dominating impact on the SSO frequency. If so, government agencies and municipalities need to re-conceptualize the role of sewer system maintenance and/or raise the intensity level of maintenance.

2. It is also possible that the solutions to the maintenance problem could be found in the optimization of the timing, and the different types of maintenance activities, new and existing. Schaaf's methodology and its like may have already been serving that purpose, and have had some successes in this area. We suggest that much more research and development may be needed. Given the significant role of the seasonal effect, it is not difficult to see that there is much room to fill in the realm of "intelligent maintenance".
3. It is not impossible that we are missing out and unaware of

some key major factors in this study. There could be new dimensions added in the future by continuing researches and experiments so that much better understanding and control of SSO can be achieved.

Section 5: Secondary Results

5.01 Groundwater Level

As we have seen in Figure 2, the groundwater level is somewhat correlated to the flow index. There is little doubt that groundwater level is a factor in the SSO problem. Common sense suggests that, when groundwater level is high, infiltration to the sewer system should also be high. In this study, we have two orthogonal dimensions along which to investigate. We study each independent variable by examining its projections in the dimension of System Load and the dimension of System Capacity respectively.

Again, in our opinion, the Load aspect of the groundwater level is included in the flow index. The question we examine here is whether groundwater levels indicate, to a degree, changes in the condition of the system.

Toward that end, we consider the average of the groundwater levels from the three wells in the study database. Let it be denoted by **WELL**, and consider, based on the model in (11),

$$(12) \quad \log(\lambda) = \mu + f\,(\mathbf{FLOW}) + \Sigma_{k=1 \text{ to } 11}\, \beta_k\, \mathbf{M}_k + \alpha\, \mathbf{Z} + \delta\, \mathbf{SCHAAF} + \theta\, \mathbf{HUGO} + \kappa\, \mathbf{T} + \gamma\, \mathbf{WELL},$$

where γ is a parameter corresponding to the variable **WELL**.

The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 118 observations.

Parameter	Estimate	p-value
γ	0.0347	0.0782

The positive value of the estimated γ suggests that a higher **WELL** value may lead to a higher likelihood of an SSO. Such a statement is merely hinted at by the fact that the p-value is 0.0782, not very strongly supported. Nevertheless, the inclusion of **WELL** in the model increases the total proportion of explained deviance to

68.08%, a 4% increase from the model in (11).

The result may very well be a consequence of sampling errors. On the other hand, there are many possible interpretations why γ is estimated positive. None of these possibilities is more acceptable than the others. We leave the interpretation of this observation open.

5.02 Rainfall

Monthly rainfall generated from USGS data were obtained. Based on the model in (11), we also considered

$$(13) \quad \log(\lambda) = \mu + f(\mathbf{FLOW}) + \Sigma_{k=1 \text{ to } 11} \beta_k \mathbf{M_k} + \alpha\, \mathbf{Z} + \delta\, \mathbf{SCHAAF} + \theta\, \mathbf{HUGO} + \kappa\, \mathbf{T} + \pi\, \mathbf{RAIN},$$

where π is a parameter corresponding to the variable Rain.

The SAS GENMOD Procedure showed the following major results, (see Appendix C for SAS output,) with 170 observations.

Parameter	Estimate	p-value
π	0.0002	0.2229

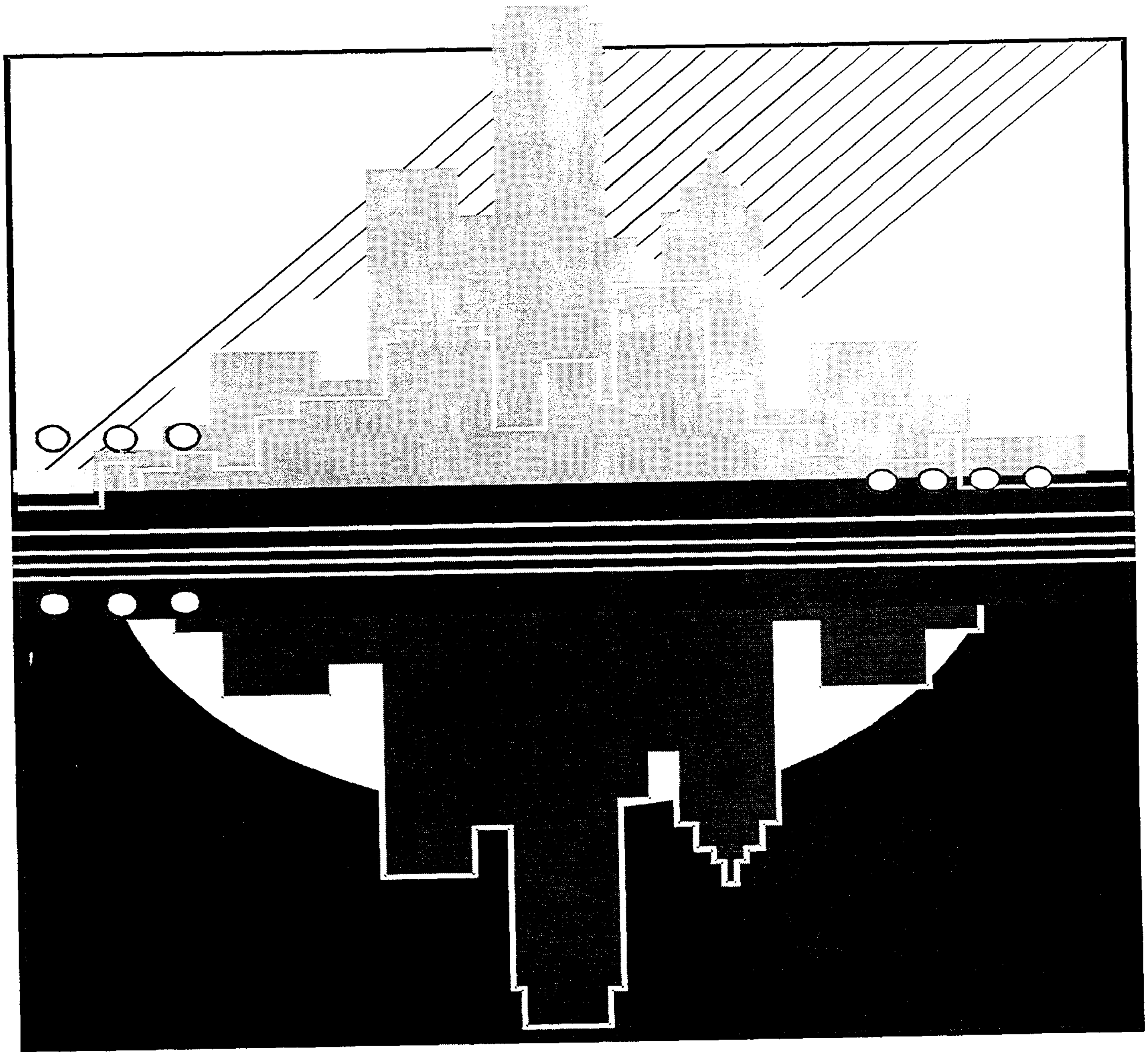
The p-value (0.2229) suggests that rainfall does not seem to add any additional power to the model as it enters the model at this point. This is not to say that rain does not affect SSO frequency, but that its effects have already been reflected by the other independent variables, particularly the Load variable, **FLOW**. This claim is supported by the analysis results with Rain entering the model at different points. Each time, the Type 1 analysis showed that the variable, Rain, was an insignificant contributor.

References:

1. Alan Agresti, A. (1990). *Categorical Data Analysis*, New York: Wiley.
2. American Society of Civil Engineers and Black & Veatch, LLP, (1998). *Optimization of Collection System Maintenance Frequencies and System Performance*, B&V Project No. 31400.
3. Camp Dresser & McKee. (1994). *Sanitary Sewer Facility Plan for the McAlpine Creek, Sugar Creek, and Irwin Creek WWTP Service Areas,* Technical report to CMU.
4. SAS Institute Inc., SAS® Technical Report P-243, *SAS/STAT® Software: The GENMOD Procedure, Release 6.09*, Cary, NC: SAS Institute Inc., 1993.
5. Schaaf, J.R. (1985). *Computerization of Sewer Maintenance Scheduling, Part 1 - Principles of Operation,* Public Works, Sept. 1985, pp. 128-129.
6. Schaaf, J.R. (1985). *Computerization of Sewer Maintenance Scheduling, Part 2 - Preliminary Results,* Public Works, Oct. 1985, pp. 64-66.
7. Stalnaker, Randy and Rigsby, Mike. (1997). *Evaluating the Effectiveness of Wastewater Collection System Maintenance,* Collection System O&M.

Appendix A: CHAMPS Manual

CHAMPS



REQUIRED DATA ELEMENTS:

COMMON DATA:

CREW CODE
CREW CHIEF:
REPORT #
DATE
JOB # (IF REQUIRED)

COSTS:

LOCATION: COMPLETE ADDRESS INFORMATION (AT LEAST ONE)

PLUS THE FOLLOWING:

OPS CODE	UNITS	UNITS	CC (5)	SVRT	TICKET #	DISTANCE
00	X	X	X			
04	X	X	X		X	X
05	X	X	X		X	X
06	X	X	X		X	X
07	X	X	X			
08	X	X	X		X	X
09	X	X	X	X		
10	X	X	X	X		
11	X	X	X			
12	X	X	X			
13	X	X	X			
14	X	X	X	X		
15	X	X	X	X		
16	X	X	X			
17	X	X	X	X		
18	X	X	X			
23	X	X	X			
24	X	X	X			
27	X	X	X			
28	X	X	X			
29	X	X	X			
30	X	X	X		X	X
31	X	X	X		X	X
32	X	X	X		X	X
33	X	X	X		X	X
34	X	X	X		X	X
35	X	X	X		X	X
36	X	X	X		X	X
37	X	X	X		X	X
38	X	X	X		X	X
39	X	X	X		X	X
99	X	X	X		X	X

DIVISION CREW CODES:

Crew codes, as defined in this document, is a three-part code used to identify a specific crew and is structured as follows:

DIVISION NO	OPERATIONS CODE	CREW NO
619	99	99

Division No:

619	Laterals, Mainline Construction, Preventive Maintenance
627	Lift Stations

Operations Code:

00	Training	
04	Lateral Replacement	
05	Lateral (NEW) Low Pressure	
06	Lateral (NEW)	
07	Main Line Construction	
08	Rapid Response	
09	Jets & Combination Machines	*
10	Rodder	*
11	Off Street	
13	Right-of-Way Mowing	
14	T.V.	*
15	Herbicide	*
16	Cleaning / Inspection MH	
17	Inspections	*
18	Checking for Connections to CMUD	
23	Reworking Laterals Installed by Contractors	
24	Reworking Main Lines Installed by Contractors	
27	Lift Station Preventive Maintenance	
28	Right-of-Way Maintenance	
30	Repair / Main Line	
31	Repair / Lateral	
32	Repair / MH	
33	Backwater Valve Installation	
34	Inflow/Infiltration	
35	Maintenance / Low Pressure	
36	Repair / Low Pressure Main	
37	Repair / Low Pressure Lateral	
38	Repair / Low Pressure Box	
39	Flush / Low Pressure Lines	
99	Emergency	

Crew No:

- Each Crew Chief is assigned a unique Crew No. which they use in combination with the above codes specifically identify the type of operation which his crew is performing. Operations Code "99" is used to signify that the crew is performing an emergency service which should be cost out separately from their routine operations. * ***-These operations affect cleaning cycles.***

UNITS:

OPERATIONS CODES	UNITS	VALID RANGE
00	HOURS	0001 - 0016
04	LOCATION	0001 - 0001
05	LOCATION	0001 - 0001
06	LOCATION	0001 - 0001
07	FOOTAGE (linear)	0000 - 0350
08	LOCATION	0001 - 0001
09	FOOTAGE (linear)	0001 - 5000
10	FOOTAGE (linear)	0001 - 3500
11	FOOTAGE (linear)	0001 - 2500
13	FOOTAGE (linear)	0001 - 15000
14	FOOTAGE (linear)	0001 - 2500
15	FOOTAGE (linear)	0001 - 3000
16	LOCATION	0001 - 0050
17	LOCATION	0001 - 0001
18	LOCATION	0001 - 0001
23	LOCATION	0001 - 0001
24	LOCATION	0001 - 0001
27	LOCATION	0001 - 0001
28	LOCATION	0001 - 0001
30	LOCATION	0000 - 0005
31	LOCATION	0000 - 0005
32	LOCATION	0000 - 0010
33	LOCATION	0001 - 0001
34	LOCATION	0001 - 0001
35	LOCATION	0001 - 0001
36	LOCATION	0001 - 0001
37	LOCATION	0001 - 0001
38	LOCATION	0001 - 0001
39	LOCATION	0001 - 0001
99	LOCATION	0001 - 0001

In the event, a value is entered which exceeds the valid range established above, the transaction will be rejected and the "Units" field flagged by reverse video on the VDT.

"Total Laterals Installed" is a field used to capture the number of laterals that are installed during the workday. In those instances where work is begun on a lateral but is not completed during the workday, an asterisk (*) is to be placed in the first position of the distance field. The number of addresses on the Job Report for lateral installation must not exceed the "Total Laterals Installed". The "Total Laterals Installed" may be between zero (if none were completed that day) and the total number of addresses (up to 10 allowed per report).

For computational reasons, the zero will be changed to a "1" in order to compute the "Cost of Work" for that address. However, a "1" will not be added to the accumulator of YTD Laterals Installed for that Crew Code.

CONDITION CODES:

1. PRIVATE TROUBLE
2. NOTHING FOUND
3. MAIN LINE BLOCKAGE
4. MAIN LINE DAMAGED BY OTHER
5. LATERAL FLAT
6. INACTIVE *
7. LATERAL DAMAGED BY OTHER
8. MH DAMAGE
9. MH TOO HIGH/LOW
10. ROOTS
11. GREASE
12. SAND/SILT
13. RAGS/PAPER/PLASTIC
14. ROCKS/BRICKS/DEBRIS
15. WIRE/CABLE/STRING
16. WOOD/STICKS/LEAVES
17. INSECTS
18. RODENTS
19. REASON: UNDETERMINED
20. POISONOUS GASES
21. EXPLOSIVE/FLAMMABLE GASES
22. ODOR
23. BUILDING BACK-UP/NO DAMAGE
24. HOUSE LOWER THAN MAIN LINE
25. BUILDING BACK-UP/DAMAGE
26. STORM/FLOOD BACK-UP
27. EROSION DAMAGE
28. SEWER LEAK
29. SEPTIC TANK PROBLEM
30.
31. ILLEGAL DISCHARGE
32. SINK OVER LATERAL
33. ACTIVE *
34. OFF-SET/CRACKED/CRUSHED
35. WORK PENDING
36. WORK COMPLETE
37. DEAD END LINE
38. INFLOW
39. INFILTRATION
40. ANOTHER DEPTs PROBLEM
41. REFERRED TO STREET DIV
42. REFERRED TO WATER DIV
43. REFERRED FROM ULOCO
44. VACTOR ONLY
45. NIGHTS ONLY
46. SINK OVER MAIN LINE
47. CAVE IN
48. MAIN LINE FLAT
49. MAIN LINE CUT
50. VANDALISM
51. PRIVATE PROPERTY DAMAGE
52. LANDSCAPING
53. OVERFLOW (SSO)
54. OVERFLOW REPORTED TO STATE
55.
56.
57. REPAIR: MAIN LINE SERVICE ORDER
58. REPAIR: LATERAL SERVICE ORDER
59. REPAIR: MH SERVICE ORDER
60.
61.
62. COMPRESSOR MAINTENANCE
63.
64. SERVICE OF EQUIPMENT
65. WATER LEAK
66. ELECTRICAL MAINTENANCE
67. PUMP MAINTENANCE
68. MOTOR MAINTENANCE
69. SOLID MH COVER INSTALLED
70. CREEK CROSSING WORK
71. TREE CUTTING WORK
72. FLOW MONITORING
73. POWER FAILURE
74. MECHANICAL FAILURE
75. HIGH WATER
76. STATION FLOODED
77. GENERATOR ACTIVATED
78. CUTTING PAVEMENT
79. BORING
80. NORMAL DIGGING: SOIL
81. WATER SOAKED: SOIL
82. HARD DIGGING: SOIL
83. ROCK EXCAVATION
84. CUT DEPTH (0' - 6')
85. CUT DEPTH (6' - 12')
86. CUT DEPTH (12' - OVER)
87. CAST IRON PIPE
88. ORNGBRG/TERRA COTTA PIPE
89. VITRIFIED CLAY PIPE
90. SMOKE TEST
91. DYE TEST
92. LATERAL BLOCKAGE
93. LATERAL CUT
94. TV TEST
95. LATERAL EXTENDED
96. LATERAL REPLACED
97. MH COVER OFF/RATTLING
98. AERIAL CROSSING DOWN
99. OUTFALL COLLAPSE

* **RESTRICTED CODES**

In order to collect data for the report (Connected / Not Connected Laterals Report), the following Condition Codes may **only** be used in conjunction with Operations Code "18" (Checking for Connections to CMUD):

06	INACTIVE
33	ACTIVE

The following Condition Codes should also be included in order to enable us to determine which kind of test was performed:

90	SMOKE TEST
91	DYE TEST
94	TV TEST

Severity Code:

0	NOT MUCH
1	LESS THAN USUAL
2	NORMAL AMOUNT
3	ALMOST BLOCKED
4	BLOCKAGE

CODES:

STREET NAME:

Spell out alphabetic names completely, e.g. Tuckaseegee; maximum of 20 characters. Use alphanumeric names of numbered streets, e.g. 4th, 22nd, 33rd, etc.

STREET DIRECTION:

N = NORTH
S = SOUTH
E = EAST
W = WEST

OFF-STREET DIRECTION:

N = NORTH
S = SOUTH
E = EAST
W = WEST

STREET TYPES:

AL = ALLEY	HY = HIGHWAY	TL = TRAIL
AV = AVENUE	LN = LANE	TR = TERRACE
BV = BOULEVARD	LP = LOOP	WY = WAY
CR = CIRCLE	PL = PLACE	
CT = COURT	PY = PARKWAY	
CV = COVE	RA = RAMP	
DR = DRIVE	RD = ROAD	
EP = EXPRESSWAY	RN = RUN	
EX = EXTENSION	RW = ROW	
FR = FREEWAY	ST = STREET	

JURISDICTION CODES:

ME = 0 = MECKLENBURG COUNTY
CH = 1 = CHARLOTTE
DA = 2 = DAVIDSON
CR = 3 = CORNELIUS
PI = 4 = PINEVILLE
MA = 5 = MATTHEWS
HU = 6 = HUNTERSVILLE
MH = 7 = MINT HILL

NO CONDITION CODE AVAILABLE:

You may run into some situations or problems for which no condition code is shown in the condition code table. In this event, enter the condition code "02" NOTHING FOUND in the condition code column. The reason "NOTHING FOUND" must be entered is because the condition code is a required data element and reports cannot be entered without a code. You may explain the reason for this condition code under the "ADDITIONAL INFORMATION" section. You should make every attempt to choose the appropriate condition code in order that we may have a record of the field conditions, which you have encountered.

TRAINING SESSIONS:

If you attend, any training sessions use the following code to indicate that:

i.e.

DIV NO	00	RADIO NO
619	00	99
627	00	99

Under "House/Block No." and "Street Name", enter the address of the location where the training was held. Under "Units", enter the number of hours that you spent in training. Under "Condition Codes", enter the code "02" NOTHING FOUND. The reason for this code is as stated above.

STREETS WHERE NO HOUSE/BLOCK NUMBER CAN BE FOUND:

All streets in Mecklenburg County have been numbered. There are some problems with the smaller towns. If you cannot find a number, and you have tried, come into the office and we will make every attempt to establish where it is that you have been from one of the maps available. The "House/Block No." is a required field.

OFF-STREET LOCATION CODES:

Off Street Cleaning Crews and most other cleaning crews will frequently work on sewer lines, which run off street. For example, an off street line might be located near 1123 South Tryon St. The line could be going east. This is how this segment of line would be coded on our job report: 1100 S TRYON ST E. This tell us that there is an off street line in the 1100 block of South Tryon Street which we cleaned in an easterly direction. The "OS" indicates the line runs off street and the direction that it runs in. Note: that we only use the main points of the compass, N, S, E, W. If the line intersects (crosses) another street and perhaps changes direction, another block, street, and/or off street direction should be recorded and the new direction indicated. Use your compass at all times to determine the OS directions!

CREW CODE COMBINATION

"00" TRAINING

6190001
6190002
6190003
6190004
6190005
6190007
6190011
6190012
6190013
6190026
6190028
6190050
6190051
6190052
6190053
6190054
6190055
6190056
6190057
6190058
6190059
6190060
6190061
6190075
6190076
6190077
6190078
6190079
6190080
6190081
6190082
6190083
6190084
6190085

6270006
6270041
6270042
6270043
6270044
6270045

"04" LATERAL REPLACEMENT

6190411
6190412
6190413
6190426
6190428
6190453
6190460
6190461
6190477

"05" LATERAL INSTALLATION (NEW) LOW PRESSURE

6190561

"06" LATERAL INSTALLATION

6190611
6190612
6190613
6190626
6190628
6190653
6190660
6190661
6190677

"07" MAIN LINE CONSTRUCTION

6190711
6190712
6190713
6190726
6190728
6190753
6190760
6190761
6190777

"08" EMERGENCY

6190851
6190875
6190883
6190884
6190885

"09" JET

6190951
6190954
6190956
6190975
6190979
6190980
6190981
6190983
6190984
6190985
6190989

"10" RODDER

6191055
6191058
6191078
6191082

"11" OFF-STREET

6191150
6191157

"13" R-O-W MOWING

6191359

"14" TV

6191452
6191476

"15" HERBICIDE

6191552

"16" INSPECTING MH

6191601
6191602
6191603
6191604
6191605
6191607
6191611
6191612
6191613
6191626
6191628
6191650
6191651
6191652
6191653
6191654
6191655

6191656
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6191658
6191659
6191660
6191661
6191675
6191676
6191677
6191678
6191679
6191680
6191681
6191682
6191683
6191684
6191685

"17" INSPECTIONS

6191701
6191702
6191703
6191704
6191705
6191707
6191711
6191712
6191713
6191726
6191728
6191750
6191751
6191752
6191753
6191754
6191755
6191756
6191757
6191758
6191759
6191760
6191761
6191775
6191776
6191777
6191778
6191779
6191780
6191781
6191782
6191783
6191784
6191785

"18" CHECKING CONNECTIONS

6191801
6191802
6191803
6191804
6191805
6191807
6191811
6191812
6191813
6191826
6191828
6191850
6191851
6191852
6191853
6191854
6191855
6191856
6191857
6191858
6191859
6191860
6191861
6191875
6191876
6191877
6191878
6191879
6191880
6191881
6191882
6191883
6191884
6191885
6192185

"23" REWORKING LATERALS INSTALLED BY CONTRACTORS

6192311
6192312
6192313
6192326
6192328
6192350
6192353
6192360
6192361
6192377

"24" REWORKING MAIN LINES INSTALLED BY CONTRACTORS

6192411
6192412
6192413
6192426
6192428
6192450
6192453
6192460
6192461

"27" LIFT STATION

6192756
6272706
6272741
6272742
6272743
6272744
6272745

"28" R-O-W MAINTENANCE

6192859

"30" REPAIR: MAIN LINE

6193011
6193012
6193013
6193026
6193028
6193050
6193053
6193060
6193061
6193077

"31" REPAIR: LATERAL

6193111
6193112
6193113
6193126
6193128
6193150

6193153
6193160
6193161
6193177

"32" REPAIR: MH

6193211
6193212
6193213
6193226
6193228
6193250
6193253
6193260
6193261
6193277

"33" BACKWATER VALVE INSTALLATION

6193302
6193304
6193308

"34" INFLOW/INFILTRATION

6193405
6193411
6193451
6193475
6193484

"35" MAINTENANCE / LOW PRESSURE

6193561

"36" REPAIR / LOW PRESSURE MAIN

6193661

"37" REPAIR / LOW PRESSURE LATERAL

6193761

"38" REPAIR / LOW PRESSURE BOX

6193861

"39" FLUSH LOW PRESSURE LINES

6193961

"99" EMERGENCY

6199901
6199902
6199903
6199904
6199905
6199907
6199950
6199951
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6279906
6279941
6279942
6279943
6279944
6279945

Appendix B: Examples of Data

SSO Data

RECORD_TYP	REPORT_N0	CREW_DIV	CREW_OPS	CREW_NO	CREW_SHIFT	RQST_MO	RQST_DA	RQST_YR	DAY_OF_WK
1	00020	619	00	02	1	04	12	1991	6
1	14949	619	00	04	1	11	27	1987	6

TOPO	ST_NAME	ST_TYPE	ST_DIR	BLOCK_NO	TOWNSHIP	OS_DIR	CONDCD_1	CONDCD_2	CONDCD_3
0131	SHERYL	CR		00642	1		03	53	11
0640	CAMELBACK	CR		10411	1		53	03	26

CONDCD_4	CONDCD_5	CONDCD_6	CONDCD_7	CONDCD_8	CONDCD_9	CONDCD_10	UNIT	LCLN_MO	LCLN_DA
00	00	00	00	00	00	00		12	13
00	00	00	00	00	00	00		03	27

LCLN_YR	LCLN_CREW_	ADDRESS	AREA	PERIMETER	BAS_MAIN_	BAS_MAIN_I	MAIN_	NAME	MN_RATIO
1990	10	00642 SHERYL CR	1048000928.47942	201249.42453	17	16	7	COFFEE	57.616
1985	09	10411 CAMELBACK CR	425587724.89385	163268.45983	26	25	15	McMULLEN	37.650

MN_WEIGHTE	MN_RATIO1	MN_WEIGHTE	AV_ADD	AV_STATUS	AV_SCORE	AV_SIDE
712.902	38.231	0.000	00642 SHERYL CR	M	75	R
649.944	32.152	0.000	10411 CAMELBACK CR	M	75	L

Daily Flow to WWTP

DATE	MCDO	SUGAR	IRWIN	MCAL_S	MCAL_N	MALLARD	MCD_PA	FLOWTO	AVGMGD
Jan-83									
Feb-83									
Mar-83									
Apr-83									
May-83									
Jun-83									
Jul-83	15.025	361.488	339.775	278.812	201.007	21.135	0.069	1202.286	38.783
Aug-83	14.929	402.903	329.553	330.720	196.196	21.478	0.054	1280.904	41.319
Sep-83	12.413	371.162	288.433	307.900	186.219	23.333	0.045	1177.092	37.971
Oct-83	12.188	313.277	324.269	325.970	197.798	23.673	0.048	1185.035	38.227
Nov-83	13.398	290.920	341.626	355.927	219.341	25.860	0.000	1247.072	
Dec-83	21.230	483.912	383.365	412.920	255.457	36.668	0.000	1572.322	50.720
Jan-84	19.840	452.800	371.802	405.320	290.171	33.593	0.000	1553.686	50.119
Feb-84	23.785	452.010	365.765	441.138	331.604	35.352	0.000	1625.869	52.447
Mar-84	24.582	491.634	408.206	491.280	371.379	36.264	0.000	1798.763	58.025
Apr-84	19.072	416.244	410.073	502.080	239.103	32.068	0.000	1599.568	51.599
May-84	19.622	430.639	393.620	458.330	210.550	24.454	0.000	1517.593	48.955
Jun-84	14.331	333.408	327.274	332.400	220.715	25.218	0.094	1239.109	39.971
Jul-84	17.187	362.380	360.190	334.970	266.916	339.096	0.311	1663.863	53.673

Yearly Maintenance Activities

FY	Code 00	Code 04	Code 05	Code 06	Code 07	Code 08	Code 09	Code 10	Code 11	Code 12	Code 13	Code 14
1980	2192		437	713	18934	9804	1362095	1258944	289689	3098	864591	105023
1981	2272		172	703	13777	10650	1466697	935267	244468	3144	658007	84290
1982	1737		38	411	18278	10058	1688291	911543	219534	4267	705213	115355
1983	2411	12	36	406	9393	9778	1592214	994798	275604	6003	732727	120901
1984	3629	20	3	510	10897	9653	1956109	1945418	299977	4454	773022	135728
1985	2691	32	19	523	11825	10138	1923786	2005060	400363	4191	875327	121106
1986	3555	47	3	540	15584	8993	1844596	1746424	475369	3740	898142	127009
1987	5877	153		468	12015	10490	2153567	1447627	400248	5989	797236	226671
1988	3739	77		528	11045	4777	2030685	1542786	476982	32	979006	272228
1989	4871	79		489	15514	2253	2318485	1320208	365841		735452	204604
1990	10053	97		559	10058	2548	2377080	1464390	196649		192055	134889
1991	14684	78		440	11084	2912	2705193	1368110	255415		519711	182082
1992	16610	107		402	2219	3527	2719894	1728731	284786		719350	205747
1993	14235	94		464	4361	3272	3770456	1983532	177115		890700	162248
1994	5884	96		433	5251	3373	4054698	2019115	278161		858877	220387
1995	8325	109		534	3359	3528	2601586	1813820	268027		964200	243188
1996	1257	82		551	4071	4252	2428514	1714696	302411		896360	192212
1997	1260	57		675	1947	4430	2600728	1372261	226041		1056795	347011
1998	1219	61		172	461	4113	2416383	1535849	154900		853080	325066

Yearly Maintenance Activities

Code 15	Code 16	Code 17	Code 18	Code 19	Code 20	Code 21	Code 22	Code 23	Code 24	Code 25	Code 26	Code 27
108552	8981	13337	3674	2960	1514	1122	15	53	95			
249149	11336	223	322	894	396	2502	1	148	221	1384	120	
295764	4552	487	220	826	2737	3033	2	162	516	9386	229	
310383	3322	982	196	656	3156	2870		12	54	9842	4	51
254383	1684	811	1004	806	3240	3601		10	29	7556	32	178
147995	1824	470	270	1299	3308	2878		8	31	6073	73	849
176431	2983	481	154	784	2149	3616		44	6	5811	55	1836
101450	4022	517	191	2058	3176	4647	8	8		6556	34	2268
135257	4589	373	94	1178	2680	3230		2	14	6734	107	1294
105704	4448	73	144	993	2776	3239		10	21	7617	100	759
100503	6483	63	193	1142	4015	2407			7	7811	121	766
119796	3859	45	168	1715	2992	2129				9919	67	805
68883	3100	66	115	703	8822	1127				12561	53	863
92380	2654	51	142	862	1282	263				4974	220	725
76444	2519	137	221	2047	518	834				2315	162	728
89820	2811	27	190	1473	40	713		11	22	16	60	754
46998	3562	49	125					10	18			627
	985	27	172					12	7			279
	1325		53					2	1			587

Yearly Maintenance Activities

Code 28	Code 30	Code 31	Code 32	Code 33	Code 34	Code 99
						48
						968
						2523
						2321
						1651
280						1963
261						2946
232						3802
102	537	341	883			2574
68	538	401	516			2132
24	653	296	392			2511
50	629	288	521			2437
55	934	384	908	55		2196
59	576	700	797	45	261	2590
57	714	698	574	77	311	2488
115	677	748	444	65	643	2586
88	673	811	418	111	427	2061
76	618	824	387	50	673	2274
119	701	949	264	60	964	3225

Ground Water Level
Highway 521

YEAR	MONTH	DAY	WELL2
1984	12	17	21.04
1984	12	18	21.07
1984	12	19	21.08
1984	12	20	21.1
1984	12	21	21.12
1984	12	22	21.14
1984	12	23	21.18
1984	12	24	21.18
1984	12	25	21.22
1984	12	26	21.26
1984	12	27	21.26
1984	12	28	21.26
1984	12	29	21.27
1984	12	30	21.3
1984	12	31	21.31
1985	1	1	21.32
1985	1	2	21.34
1985	1	3	21.31
1985	1	4	21.03
1985	1	5	20.9
1985	1	6	20.77
1985	1	7	20.51
1985	1	8	20.47
1985	1	9	20.45
1985	1	10	20.36
1985	1	11	20.27
1985	1	12	20.25
1985	1	13	20.18
1985	1	14	20.11
1985	1	15	20.12
1985	1	16	20.15
1985	1	17	20.06
1985	1	18	20.04
1985	1	19	20.04
1985	1	20	20.07
1985	1	21	20.14
1985	1	22	20.14
1985	1	23	20.14
1985	1	24	20.14
1985	1	25	20.13
1985	1	26	20.22
1985	1	27	20.25
1985	1	28	20.23
1985	1	29	20.28
1985	1	30	20.33
1985	1	31	20.33
1985	2	1	20.21
1985	2	2	19.79

Rainfall Data

SSODA	Rain	trace	SSOMO	SSOYR
1	0	T	1	1983
2	79	0	1	1983
3	2	0	1	1983
4	0	0	1	1983
5	0	0	1	1983
6	0	0	1	1983
7	0	0	1	1983
8	0	0	1	1983
9	0	T	1	1983
10	0	T	1	1983
11	0	T	1	1983
12	8	0	1	1983
13	0	0	1	1983
14	0	0	1	1983
15	0	0	1	1983
16	0	0	1	1983
17	0	0	1	1983
18	0	0	1	1983
19	0	0	1	1983
20	5	0	1	1983
21	71	0	1	1983
22	31	0	1	1983
23	46	0	1	1983
24	0	0	1	1983
25	0	0	1	1983
26	0	0	1	1983
27	9	0	1	1983
28	2	0	1	1983
29	0	0	1	1983
30	0	T	1	1983
31	0	0	1	1983
1	0	0	2	1983
2	125	0	2	1983
3	0	0	2	1983
4	0	0	2	1983
5	0	T	2	1983
6	102	0	2	1983
7	0	0	2	1983
8	0	0	2	1983
9	0	0	2	1983
10	39	0	2	1983
11	30	0	2	1983
12	0	0	2	1983
13	2	0	2	1983
14	131	0	2	1983
15	0	0	2	1983
16	0	0	2	1983
17	0	0	2	1983

Appendix C: SAS Outputs

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	168	730.1330	4.3460
Scaled Deviance	168	168.0000	1.0000
Pearson Chi-Square	168	750.7482	4.4687
Scaled Pearson X2	168	172.7435	1.0282
Log Likelihood	.	1589.1238	.

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT	1	2.2584	0.1822	153.6556	0.0001
FLOW	1	0.8789	0.2077	17.9146	0.0001
SCALE	0	2.0847	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	168	.	.	.	.
FLOW	730.1330	1	168	16.9781	0.0001	16.9781	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	168	16.9781	0.0001	16.9781	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	157	536.5501	3.4175
Scaled Deviance	157	157.0000	1.0000
Pearson Chi-Square	157	515.6798	3.2846
Scaled Pearson X2	157	150.8931	0.9611
Log Likelihood	.	2049.1989	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.7535	0.1914	206.9883	0.0001
FLOW		1	0.5554	0.1915	8.4061	0.0037
SSOMO	1	1	0.0919	0.1358	0.4583	0.4984
SSOMO	2	1	0.0114	0.1388	0.0068	0.9344
SSOMO	3	1	-0.0039	0.1391	0.0008	0.9776
SSOMO	4	1	-0.1964	0.1465	1.7970	0.1801
SSOMO	5	1	-0.2805	0.1494	3.5243	0.0605
SSOMO	6	1	-0.4457	0.1595	7.8118	0.0052
SSOMO	7	1	-0.5861	0.1627	12.9790	0.0003
SSOMO	8	1	-0.6563	0.1653	15.7556	0.0001
SSOMO	9	1	-0.5614	0.1676	11.2170	0.0008
SSOMO	10	1	-0.2856	0.1518	3.5399	0.0599
SSOMO	11	1	-0.0819	0.1430	0.3276	0.5671
SSOMO	12	0	0.0000	0.0000	.	.
SCALE		0	1.8487	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	157	.	.	.	.
FLOW	730.1330	1	157	21.5910	0.0001	21.5910	0.0001
SSOMO	536.5501	11	157	5.1495	0.0001	56.6443	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	157	8.1867	0.0048	8.1867	0.0042
SSOMO	11	157	5.1495	0.0001	56.6443	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	404.5614	2.5933
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	404.5915	2.5935
Scaled Pearson X2	156	156.0116	1.0001
Log Likelihood	.	2725.8894	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.8952	0.1658	304.9694	0.0001
FLOW		1	0.3765	0.1652	5.1925	0.0227
SSOMO	1	1	0.0807	0.1181	0.4673	0.4942
SSOMO	2	1	-0.0092	0.1209	0.0058	0.9394
SSOMO	3	1	-0.0074	0.1210	0.0037	0.9513
SSOMO	4	1	-0.2185	0.1276	2.9299	0.0870
SSOMO	5	1	-0.2954	0.1301	5.1537	0.0232
SSOMO	6	1	-0.4794	0.1390	11.8976	0.0006
SSOMO	7	1	-0.6060	0.1418	18.2713	0.0001
SSOMO	8	1	-0.6739	0.1440	21.8906	0.0001
SSOMO	9	1	-0.5819	0.1461	15.8556	0.0001
SSOMO	10	1	-0.2995	0.1322	5.1323	0.0235
SSOMO	11	1	-0.0866	0.1246	0.4827	0.4872
SSOMO	12	0	0.0000	0.0000	.	.
ZMEAN		1	-0.4268	0.0607	49.5077	0.0001
SCALE		0	1.6104	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	28.4527	0.0001	28.4527	0.0001
SSOMO	536.5501	11	156	6.7860	0.0001	74.6461	0.0001
ZMEAN	404.5614	1	156	50.8952	0.0001	50.8952	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	5.1159	0.0251	5.1159	0.0237
SSOMO	11	156	7.1279	0.0001	78.4066	0.0001
ZMEAN	1	156	50.8952	0.0001	50.8952	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	294.0519	1.8849
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	290.0325	1.8592
Scaled Pearson X2	156	153.8676	0.9863
Log Likelihood	.	3779.6372	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	3.0348	0.1417	458.9297	0.0001
FLOW		1	0.1841	0.1431	1.6546	0.1983
SSOMO	1	1	0.0721	0.1008	0.5121	0.4742
SSOMO	2	1	-0.0240	0.1031	0.0544	0.8157
SSOMO	3	1	-0.0026	0.1033	0.0006	0.9797
SSOMO	4	1	-0.2321	0.1088	4.5481	0.0330
SSOMO	5	1	-0.3037	0.1110	7.4931	0.0062
SSOMO	6	1	-0.5049	0.1185	18.1691	0.0001
SSOMO	7	1	-0.6126	0.1208	25.7132	0.0001
SSOMO	8	1	-0.6748	0.1228	30.2055	0.0001
SSOMO	9	1	-0.5943	0.1245	22.7870	0.0001
SSOMO	10	1	-0.2996	0.1127	7.0717	0.0078
SSOMO	11	1	-0.0929	0.1062	0.7645	0.3819
SSOMO	12	0	0.0000	0.0000	.	.
Z08		1	-0.3188	0.0296	115.7931	0.0001
SCALE		0	1.3729	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	39.1456	0.0001	39.1456	0.0001
SSOMO	536.5501	11	156	9.3363	0.0001	102.6993	0.0001
Z08	294.0519	1	156	128.6498	0.0001	128.6498	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	1.6436	0.2017	1.6436	0.1998
SSOMO	11	156	9.9550	0.0001	109.5053	0.0001
Z08	1	156	128.6498	0.0001	128.6498	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	515.1892	3.3025
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	499.4596	3.2017
Scaled Pearson X2	156	151.2371	0.9695
Log Likelihood	.	2123.8039	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.9391	0.1996	216.8169	0.0001
FLOW		1	0.3285	0.2077	2.5029	0.1136
SSOMO	1	1	0.0982	0.1337	0.5393	0.4627
SSOMO	2	1	0.0090	0.1365	0.0043	0.9476
SSOMO	3	1	0.0160	0.1374	0.0136	0.9071
SSOMO	4	1	-0.1987	0.1440	1.9029	0.1678
SSOMO	5	1	-0.2746	0.1470	3.4900	0.0617
SSOMO	6	1	-0.4607	0.1568	8.6354	0.0033
SSOMO	7	1	-0.5929	0.1599	13.7579	0.0002
SSOMO	8	1	-0.6577	0.1625	16.3802	0.0001
SSOMO	9	1	-0.5831	0.1649	12.5106	0.0004
SSOMO	10	1	-0.2943	0.1492	3.8898	0.0486
SSOMO	11	1	-0.0884	0.1406	0.3951	0.5296
SSOMO	12	0	0.0000	0.0000	.	.
Z09S		1	0.0851	0.0328	6.7297	0.0095
SCALE		0	1.8173	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	22.3430	0.0001	22.3430	0.0001
SSOMO	536.5501	11	156	5.3288	0.0001	58.6172	0.0001
ZO9S	515.1892	1	156	6.4681	0.0120	6.4681	0.0110

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	2.4822	0.1172	2.4822	0.1151
SSOMO	11	156	5.5477	0.0001	61.0250	0.0001
ZO9S	1	156	6.4681	0.0120	6.4681	0.0110

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	404.5362	2.5932
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	396.9199	2.5444
Scaled Pearson X2	156	153.0629	0.9812
Log Likelihood	.	2726.0643	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.6887	0.1697	250.8842	0.0001
FLOW		1	0.6255	0.1683	13.8100	0.0002
SSOMO	1	1	0.0915	0.1181	0.5999	0.4386
SSOMO	2	1	0.0152	0.1209	0.0158	0.9000
SSOMO	3	1	-0.0110	0.1209	0.0083	0.9275
SSOMO	4	1	-0.1971	0.1276	2.3855	0.1225
SSOMO	5	1	-0.2807	0.1301	4.6571	0.0309
SSOMO	6	1	-0.4434	0.1390	10.1706	0.0014
SSOMO	7	1	-0.5968	0.1419	17.6926	0.0001
SSOMO	8	1	-0.6740	0.1441	21.8824	0.0001
SSOMO	9	1	-0.5690	0.1463	15.1342	0.0001
SSOMO	10	1	-0.2981	0.1323	5.0731	0.0243
SSOMO	11	1	-0.0739	0.1247	0.3514	0.5533
SSOMO	12	0	0.0000	0.0000	.	.
Z10S		1	-0.2211	0.0321	47.4430	0.0001
SCALE		0	1.6103	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	28.4544	0.0001	28.4544	0.0001
SSOMO	536.5501	11	156	6.7864	0.0001	74.6508	0.0001
Z10S	404.5362	1	156	50.9081	0.0001	50.9081	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	13.4210	0.0003	13.4210	0.0002
SSOMO	11	156	7.0417	0.0001	77.4586	0.0001
Z10S	1	156	50.9081	0.0001	50.9081	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	451.9539	2.8971
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	452.5507	2.9010
Scaled Pearson X2	156	156.2060	1.0013
Log Likelihood	.	2431.8697	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.9798	0.1778	280.8970	0.0001
FLOW		1	0.2882	0.1794	2.5805	0.1082
SSOMO	1	1	0.0886	0.1250	0.5026	0.4784
SSOMO	2	1	-0.0038	0.1278	0.0009	0.9760
SSOMO	3	1	0.0073	0.1281	0.0032	0.9547
SSOMO	4	1	-0.2120	0.1349	2.4684	0.1162
SSOMO	5	1	-0.2854	0.1376	4.3053	0.0380
SSOMO	6	1	-0.4767	0.1469	10.5279	0.0012
SSOMO	7	1	-0.6111	0.1498	16.6370	0.0001
SSOMO	8	1	-0.6747	0.1523	19.6365	0.0001
SSOMO	9	1	-0.5919	0.1545	14.6826	0.0001
SSOMO	10	1	-0.3025	0.1398	4.6812	0.0305
SSOMO	11	1	-0.0890	0.1317	0.4565	0.4993
SSOMO	12	0	0.0000	0.0000	.	.
Z11		1	-0.1710	0.0321	28.4015	0.0001
SCALE		0	1.7021	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	25.4691	0.0001	25.4691	0.0001
SSOMO	536.5501	11	156	6.0744	0.0001	66.8186	0.0001
Z11	451.9539	1	156	29.1999	0.0001	29.1999	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	2.5597	0.1116	2.5597	0.1096
SSOMO	11	156	6.5216	0.0001	71.7378	0.0001
Z11	1	156	29.1999	0.0001	29.1999	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	438.6003	2.8115
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	435.3084	2.7904
Scaled Pearson X2	156	154.8291	0.9925
Log Likelihood	.	2508.2851	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.9111	0.1772	269.8660	0.0001
FLOW		1	0.3482	0.1797	3.7557	0.0526
SSOMO	1	1	0.1004	0.1231	0.6654	0.4147
SSOMO	2	1	0.0123	0.1259	0.0095	0.9223
SSOMO	3	1	0.0161	0.1262	0.0163	0.8985
SSOMO	4	1	-0.1983	0.1329	2.2276	0.1356
SSOMO	5	1	-0.2750	0.1355	4.1160	0.0425
SSOMO	6	1	-0.4607	0.1446	10.1481	0.0014
SSOMO	7	1	-0.5910	0.1476	16.0441	0.0001
SSOMO	8	1	-0.6571	0.1500	19.2023	0.0001
SSOMO	9	1	-0.5800	0.1521	14.5377	0.0001
SSOMO	10	1	-0.2960	0.1376	4.6250	0.0315
SSOMO	11	1	-0.0870	0.1297	0.4501	0.5023
SSOMO	12	0	0.0000	0.0000	.	.
Z13		1	-0.1633	0.0268	37.1400	0.0001
SCALE		0	1.6768	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	26.2445	0.0001	26.2445	0.0001
SSOMO	536.5501	11	156	6.2594	0.0001	68.8530	0.0001
Z13	438.6003	1	156	34.8385	0.0001	34.8385	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	3.6939	0.0564	3.6939	0.0546
SSOMO	11	156	6.5881	0.0001	72.4687	0.0001
Z13	1	156	34.8385	0.0001	34.8385	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	533.0097	3.4167
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	510.2492	3.2708
Scaled Pearson X2	156	149.3385	0.9573
Log Likelihood	.	2050.1894	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.7935	0.1949	205.4306	0.0001
FLOW		1	0.5021	0.1983	6.4117	0.0113
SSOMO	1	1	0.1009	0.1360	0.5498	0.4584
SSOMO	2	1	0.0179	0.1389	0.0167	0.8973
SSOMO	3	1	0.0077	0.1396	0.0031	0.9558
SSOMO	4	1	-0.1903	0.1466	1.6845	0.1943
SSOMO	5	1	-0.2732	0.1496	3.3356	0.0678
SSOMO	6	1	-0.4426	0.1595	7.7032	0.0055
SSOMO	7	1	-0.5840	0.1627	12.8905	0.0003
SSOMO	8	1	-0.6529	0.1654	15.5922	0.0001
SSOMO	9	1	-0.5634	0.1676	11.2980	0.0008
SSOMO	10	1	-0.2852	0.1517	3.5330	0.0602
SSOMO	11	1	-0.0832	0.1430	0.3388	0.5605
SSOMO	12	0	0.0000	0.0000	.	.
Z14S		1	-0.0354	0.0349	1.0281	0.3106
SCALE		0	1.8484	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	21.5960	0.0001	21.5960	0.0001
SSOMO	536.5501	11	156	5.1507	0.0001	56.6574	0.0001
Z14S	533.0097	1	156	1.0362	0.3103	1.0362	0.3087

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	6.2917	0.0132	6.2917	0.0121
SSOMO	11	156	5.2112	0.0001	57.3229	0.0001
Z14S	1	156	1.0362	0.3103	1.0362	0.3087

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	160
Missing Values	39

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	146	434.4827	2.9759
Scaled Deviance	146	146.0000	1.0000
Pearson Chi-Square	146	428.2620	2.9333
Scaled Pearson X2	146	143.9097	0.9857
Log Likelihood	.	2240.7790	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.8933	0.1803	257.6265	0.0001
FLOW		1	0.3634	0.1825	3.9642	0.0465
SSOMO	1	1	0.0500	0.1296	0.1490	0.6994
SSOMO	2	1	-0.0283	0.1322	0.0460	0.8302
SSOMO	3	1	-0.0104	0.1321	0.0061	0.9376
SSOMO	4	1	-0.2068	0.1387	2.2243	0.1359
SSOMO	5	1	-0.2985	0.1421	4.4134	0.0357
SSOMO	6	1	-0.4704	0.1512	9.6775	0.0019
SSOMO	7	1	-0.5957	0.1553	14.7207	0.0001
SSOMO	8	1	-0.6809	0.1587	18.4192	0.0001
SSOMO	9	1	-0.5997	0.1613	13.8157	0.0002
SSOMO	10	1	-0.2876	0.1445	3.9596	0.0466
SSOMO	11	1	-0.0889	0.1334	0.4434	0.5055
SSOMO	12	0	0.0000	0.0000	.	.
Z15		1	-0.2296	0.0431	28.3397	0.0001
SCALE		0	1.7251	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	782.4079	0	146	.	.	.	.
FLOW	708.9951	1	146	24.6690	0.0001	24.6690	0.0001
SSOMO	527.3693	11	146	5.5484	0.0001	61.0321	0.0001
Z15	434.4827	1	146	31.2129	0.0001	31.2129	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	146	3.9228	0.0495	3.9228	0.0476
SSOMO	11	146	5.5705	0.0001	61.2754	0.0001
Z15	1	146	31.2129	0.0001	31.2129	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	511.8627	3.2812
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	491.6963	3.1519
Scaled Pearson X2	156	149.8539	0.9606
Log Likelihood	.	2138.1129	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.7388	0.1905	206.6496	0.0001
FLOW		1	0.5550	0.1913	8.4156	0.0037
SSOMO	1	1	0.1070	0.1331	0.6455	0.4217
SSOMO	2	1	0.0284	0.1361	0.0435	0.8347
SSOMO	3	1	0.0117	0.1364	0.0073	0.9319
SSOMO	4	1	-0.1813	0.1436	1.5935	0.2068
SSOMO	5	1	-0.2661	0.1465	3.2984	0.0693
SSOMO	6	1	-0.4313	0.1563	7.6088	0.0058
SSOMO	7	1	-0.5746	0.1595	12.9792	0.0003
SSOMO	8	1	-0.6451	0.1621	15.8448	0.0001
SSOMO	9	1	-0.5556	0.1643	11.4388	0.0007
SSOMO	10	1	-0.2805	0.1487	3.5580	0.0593
SSOMO	11	1	-0.0805	0.1402	0.3295	0.5659
SSOMO	12	0	0.0000	0.0000	.	.
Z16		1	0.0875	0.0317	7.6293	0.0057
SCALE		0	1.8114	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	22.4882	0.0001	22.4882	0.0001
SSOMO	536.5501	11	156	5.3635	0.0001	58.9981	0.0001
Z16	511.8627	1	156	7.5240	0.0068	7.5240	0.0061

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	8.1952	0.0048	8.1952	0.0042
SSOMO	11	156	5.3736	0.0001	59.1100	0.0001
Z16	1	156	7.5240	0.0068	7.5240	0.0061

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	511.8627	3.2812
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	491.6963	3.1519
Scaled Pearson X2	156	149.8539	0.9606
Log Likelihood	.	2138.1129	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.7388	0.1905	206.6496	0.0001
FLOW		1	0.5550	0.1913	8.4156	0.0037
SSOMO	1	1	0.1070	0.1331	0.6455	0.4217
SSOMO	2	1	0.0284	0.1361	0.0435	0.8347
SSOMO	3	1	0.0117	0.1364	0.0073	0.9319
SSOMO	4	1	-0.1813	0.1436	1.5935	0.2068
SSOMO	5	1	-0.2661	0.1465	3.2984	0.0693
SSOMO	6	1	-0.4313	0.1563	7.6088	0.0058
SSOMO	7	1	-0.5746	0.1595	12.9792	0.0003
SSOMO	8	1	-0.6451	0.1621	15.8448	0.0001
SSOMO	9	1	-0.5556	0.1643	11.4388	0.0007
SSOMO	10	1	-0.2805	0.1487	3.5580	0.0593
SSOMO	11	1	-0.0805	0.1402	0.3295	0.5659
SSOMO	12	0	0.0000	0.0000	.	.
Z16		1	0.0875	0.0317	7.6293	0.0057
SCALE		0	1.8114	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	22.4882	0.0001	22.4882	0.0001
SSOMO	536.5501	11	156	5.3635	0.0001	58.9981	0.0001
Z16	511.8627	1	156	7.5240	0.0068	7.5240	0.0061

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	8.1952	0.0048	8.1952	0.0042
SSOMO	11	156	5.3736	0.0001	59.1100	0.0001
Z16	1	156	7.5240	0.0068	7.5240	0.0061

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	156	372.4674	2.3876
Scaled Deviance	156	156.0000	1.0000
Pearson Chi-Square	156	372.7389	2.3894
Scaled Pearson X2	156	156.1137	1.0007
Log Likelihood	.	2967.4892	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.9492	0.1583	347.2364	0.0001
FLOW		1	0.2999	0.1588	3.5648	0.0590
SSOMO	1	1	0.0568	0.1134	0.2505	0.6167
SSOMO	2	1	-0.0352	0.1161	0.0920	0.7617
SSOMO	3	1	-0.0252	0.1161	0.0470	0.8284
SSOMO	4	1	-0.2433	0.1225	3.9438	0.0470
SSOMO	5	1	-0.3185	0.1249	6.5012	0.0108
SSOMO	6	1	-0.5096	0.1334	14.5908	0.0001
SSOMO	7	1	-0.6109	0.1360	20.1758	0.0001
SSOMO	8	1	-0.6774	0.1382	24.0263	0.0001
SSOMO	9	1	-0.5863	0.1401	17.5140	0.0001
SSOMO	10	1	-0.2985	0.1268	5.5405	0.0186
SSOMO	11	1	-0.0906	0.1195	0.5742	0.4486
SSOMO	12	0	0.0000	0.0000	.	.
Z17		1	-0.2872	0.0366	61.6229	0.0001
SCALE		0	1.5452	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	156	.	.	.	.
FLOW	730.1330	1	156	30.9043	0.0001	30.9043	0.0001
SSOMO	536.5501	11	156	7.3707	0.0001	81.0781	0.0001
Z17	372.4674	1	156	68.7225	0.0001	68.7225	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	156	3.5262	0.0623	3.5262	0.0604
SSOMO	11	156	7.5940	0.0001	83.5343	0.0001
Z17	1	156	68.7225	0.0001	68.7225	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	155	368.5117	2.3775
Scaled Deviance	155	155.0000	1.0000
Pearson Chi-Square	155	370.6390	2.3912
Scaled Pearson X2	155	155.8948	1.0058
Log Likelihood	.	2980.9482	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	3.2263	0.1800	321.3531	0.0001
FLOW		1	0.0369	0.1823	0.0410	0.8395
SSOMO	1	1	0.1102	0.1134	0.9447	0.3311
SSOMO	2	1	0.0085	0.1159	0.0053	0.9418
SSOMO	3	1	0.0454	0.1168	0.1514	0.6972
SSOMO	4	1	-0.1992	0.1223	2.6519	0.1034
SSOMO	5	1	-0.2677	0.1249	4.5939	0.0321
SSOMO	6	1	-0.4811	0.1330	13.0889	0.0003
SSOMO	7	1	-0.6065	0.1357	19.9766	0.0001
SSOMO	8	1	-0.6630	0.1379	23.1032	0.0001
SSOMO	9	1	-0.6186	0.1401	19.4852	0.0001
SSOMO	10	1	-0.3150	0.1266	6.1904	0.0128
SSOMO	11	1	-0.0972	0.1194	0.6628	0.4156
SSOMO	12	0	0.0000	0.0000	.	.
ZMEAN		1	-0.5447	0.0646	71.0370	0.0001
SCHAAF		1	-0.3188	0.0829	14.8046	0.0001

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
SCALE	0	1.5419	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	155	.	.	.	.
FLOW	730.1330	1	155	31.0358	0.0001	31.0358	0.0001
SSOMO	536.5501	11	155	7.4021	0.0001	81.4231	0.0001
ZMEAN	404.5614	1	155	55.5158	0.0001	55.5158	0.0001
SCHAAF	368.5117	1	155	15.1629	0.0001	15.1629	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	155	0.0410	0.8399	0.0410	0.8396
SSOMO	11	155	8.4125	0.0001	92.5372	0.0001
ZMEAN	1	155	70.5887	0.0001	70.5887	0.0001
SCHAAF	1	155	15.1629	0.0001	15.1629	0.0001

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	154	341.2245	2.2157
Scaled Deviance	154	154.0000	1.0000
Pearson Chi-Square	154	345.8812	2.2460
Scaled Pearson X2	154	156.1016	1.0136
Log Likelihood	.	3204.7177	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	3.0947	0.1797	296.5907	0.0001
FLOW		1	0.1477	0.1803	0.6710	0.4127
SSOMO	1	1	0.1036	0.1094	0.8954	0.3440
SSOMO	2	1	0.0064	0.1118	0.0032	0.9546
SSOMO	3	1	0.0311	0.1127	0.0759	0.7830
SSOMO	4	1	-0.2025	0.1181	2.9428	0.0863
SSOMO	5	1	-0.2741	0.1205	5.1725	0.0229
SSOMO	6	1	-0.4779	0.1284	13.8475	0.0002
SSOMO	7	1	-0.6025	0.1310	21.1491	0.0001
SSOMO	8	1	-0.6625	0.1332	24.7512	0.0001
SSOMO	9	1	-0.6063	0.1354	20.0432	0.0001
SSOMO	10	1	-0.3098	0.1223	6.4216	0.0113
SSOMO	11	1	-0.0931	0.1152	0.6526	0.4192
SSOMO	12	0	0.0000	0.0000	.	.
ZMEAN		1	-0.5015	0.0647	60.0737	0.0001
SCHAAF		1	-0.2468	0.0831	8.8148	0.0030

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
HUGO	1	0.3124	0.0861	13.1685	0.0003
SCALE	0	1.4885	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	154	.	.	.	.
FLOW	730.1330	1	154	33.3015	0.0001	33.3015	0.0001
SSOMO	536.5501	11	154	7.9425	0.0001	87.3670	0.0001
ZMEAN	404.5614	1	154	59.5685	0.0001	59.5685	0.0001
SCHAAF	368.5117	1	154	16.2698	0.0001	16.2698	0.0001
HUGO	341.2245	1	154	12.3151	0.0006	12.3151	0.0004

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	154	0.6681	0.4150	0.6681	0.4137
SSOMO	11	154	8.7358	0.0001	96.0940	0.0001
ZMEAN	1	154	58.8278	0.0001	58.8278	0.0001
SCHAAF	1	154	8.9270	0.0033	8.9270	0.0028
HUGO	1	154	12.3151	0.0006	12.3151	0.0004

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	153	335.2780	2.1914
Scaled Deviance	153	153.0000	1.0000
Pearson Chi-Square	153	338.8320	2.2146
Scaled Pearson X2	153	154.6218	1.0106
Log Likelihood	.	3241.7346	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	2.2540	0.5531	16.6088	0.0001
FLOW		1	1.9856	1.1548	2.9563	0.0855
FLOW*FLOW		1	-0.9634	0.5974	2.6002	0.1069
SSOMO	1	1	0.1149	0.1090	1.1107	0.2919
SSOMO	2	1	0.0007	0.1113	0.0000	0.9948
SSOMO	3	1	0.0245	0.1121	0.0477	0.8270
SSOMO	4	1	-0.2122	0.1175	3.2590	0.0710
SSOMO	5	1	-0.2901	0.1202	5.8218	0.0158
SSOMO	6	1	-0.4824	0.1277	14.2613	0.0002
SSOMO	7	1	-0.6151	0.1305	22.2223	0.0001
SSOMO	8	1	-0.6765	0.1327	26.0023	0.0001
SSOMO	9	1	-0.5943	0.1349	19.4048	0.0001
SSOMO	10	1	-0.3065	0.1216	6.3506	0.0117
SSOMO	11	1	-0.0836	0.1148	0.5309	0.4662
SSOMO	12	0	0.0000	0.0000	.	.
ZMEAN		1	-0.4984	0.0641	60.3658	0.0001

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
SCHAAF	1	-0.2229	0.0836	7.1064	0.0077
HUGO	1	0.2971	0.0861	11.9085	0.0006
SCALE	0	1.4803	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	153	.	.	.	.
FLOW	730.1330	1	153	33.6720	0.0001	33.6720	0.0001
FLOW*FLOW	725.3169	1	153	2.1977	0.1403	2.1977	0.1382
SSOMO	525.8227	11	153	8.2761	0.0001	91.0367	0.0001
ZMEAN	387.8551	1	153	62.9598	0.0001	62.9598	0.0001
SCHAAF	359.7997	1	153	12.8027	0.0005	12.8027	0.0003
HUGO	335.2780	1	153	11.1902	0.0010	11.1902	0.0008

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	153	3.0946	0.0805	3.0946	0.0786
FLOW*FLOW	1	153	2.7136	0.1015	2.7136	0.0995
SSOMO	11	153	9.0222	0.0001	99.2446	0.0001
ZMEAN	1	153	59.1835	0.0001	59.1835	0.0001
SCHAAF	1	153	7.1980	0.0081	7.1980	0.0073
HUGO	1	153	11.1902	0.0010	11.1902	0.0008

The GENMOD Procedure

Model Information

Description	Value
Data Set	WORK.AABBCC
Distribution	POISSON
Link Function	LOG
Dependent Variable	SSO
Observations Used	170
Missing Values	29

Class Level Information

Class	Levels	Values
SSOMO	12	1 2 3 4 5 6 7 8 9 10 11 12

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	152	289.0429	1.9016
Scaled Deviance	152	152.0000	1.0000
Pearson Chi-Square	152	295.4015	1.9434
Scaled Pearson X2	152	155.3438	1.0220
Log Likelihood	.	3747.8608	.

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT		1	-119.3656	24.4274	23.8783	0.0001
FLOW		1	2.5839	1.0875	5.6452	0.0175
FLOW*FLOW		1	-1.4066	0.5684	6.1230	0.0133
SSOMO	1	1	0.1135	0.1018	1.2436	0.2648
SSOMO	2	1	-0.0200	0.1038	0.0372	0.8471
SSOMO	3	1	0.0312	0.1048	0.0886	0.7660
SSOMO	4	1	-0.2321	0.1097	4.4815	0.0343
SSOMO	5	1	-0.3067	0.1122	7.4744	0.0063
SSOMO	6	1	-0.5159	0.1191	18.7664	0.0001
SSOMO	7	1	-0.6359	0.1216	27.3356	0.0001
SSOMO	8	1	-0.6908	0.1237	31.1805	0.0001
SSOMO	9	1	-0.6213	0.1256	24.4840	0.0001
SSOMO	10	1	-0.3215	0.1133	8.0528	0.0045
SSOMO	11	1	-0.0883	0.1069	0.6818	0.4090
SSOMO	12	0	0.0000	0.0000	.	.
ZMEAN		1	-0.2324	0.0815	8.1209	0.0044

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
SCHAAF	1	-0.5280	0.0981	28.9900	0.0001
HUGO	1	0.3658	0.0819	19.9411	0.0001
SSOYR	1	0.0611	0.0123	24.8103	0.0001
SCALE	0	1.3790	0.0000	.	.

NOTE: The scale parameter was estimated by the square root of DEVIANCE/DOF.

LR Statistics For Type 1 Analysis

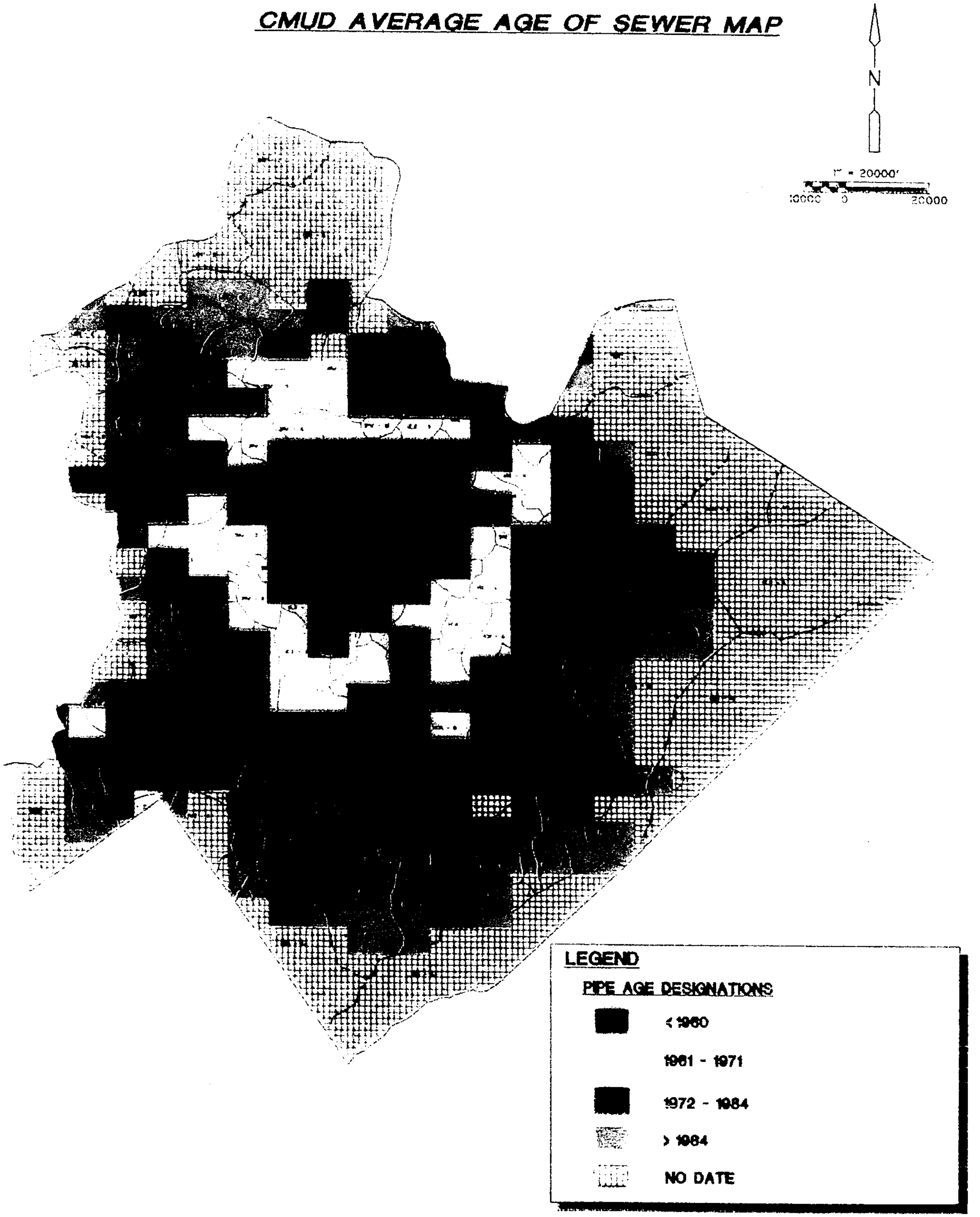
Source	Deviance	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
INTERCEPT	803.9205	0	152	.	.	.	.
FLOW	730.1330	1	152	38.8029	0.0001	38.8029	0.0001
FLOW*FLOW	725.3169	1	152	2.5326	0.1136	2.5326	0.1115
SSOMO	525.8227	11	152	9.5372	0.0001	104.9087	0.0001
ZMEAN	387.8551	1	152	72.5535	0.0001	72.5535	0.0001
SCHAAF	359.7997	1	152	14.7536	0.0002	14.7536	0.0001
HUGO	335.2780	1	152	12.8953	0.0004	12.8953	0.0003
SSOYR	289.0429	1	152	24.3138	0.0001	24.3138	0.0001

LR Statistics For Type 3 Analysis

Source	NDF	DDF	F	Pr>F	ChiSquare	Pr>Chi
FLOW	1	152	5.9807	0.0156	5.9807	0.0145
FLOW*FLOW	1	152	6.5011	0.0118	6.5011	0.0108
SSOMO	11	152	10.9671	0.0001	120.6378	0.0001
ZMEAN	1	152	8.0068	0.0053	8.0068	0.0047
SCHAAF	1	152	28.7450	0.0001	28.7450	0.0001
HUGO	1	152	18.6109	0.0001	18.6109	0.0001
SSOYR	1	152	24.3138	0.0001	24.3138	0.0001

Appendix D: Figures

CMUD AVERAGE AGE OF SEWER MAP



CHARLOTTE-MECKLENBURG UTILITY DEPARTMENT

AVERAGE AGE OF SEWER ANALYSIS

CDM
environmental engineers, scientists, planners, & management consultants

FIGURE 2: Flow vs. Groundwater

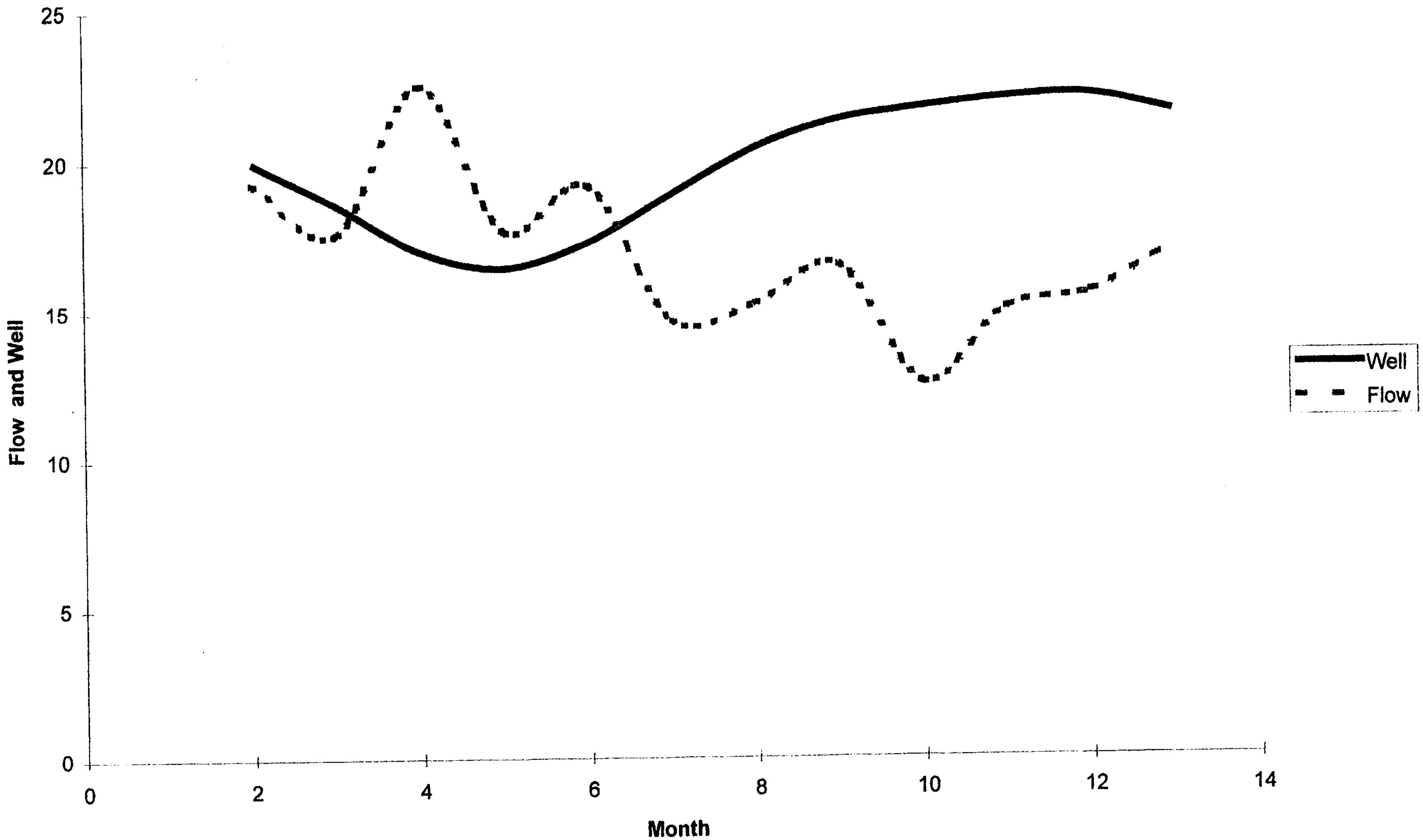


FIGURE 3: SSO Frequency

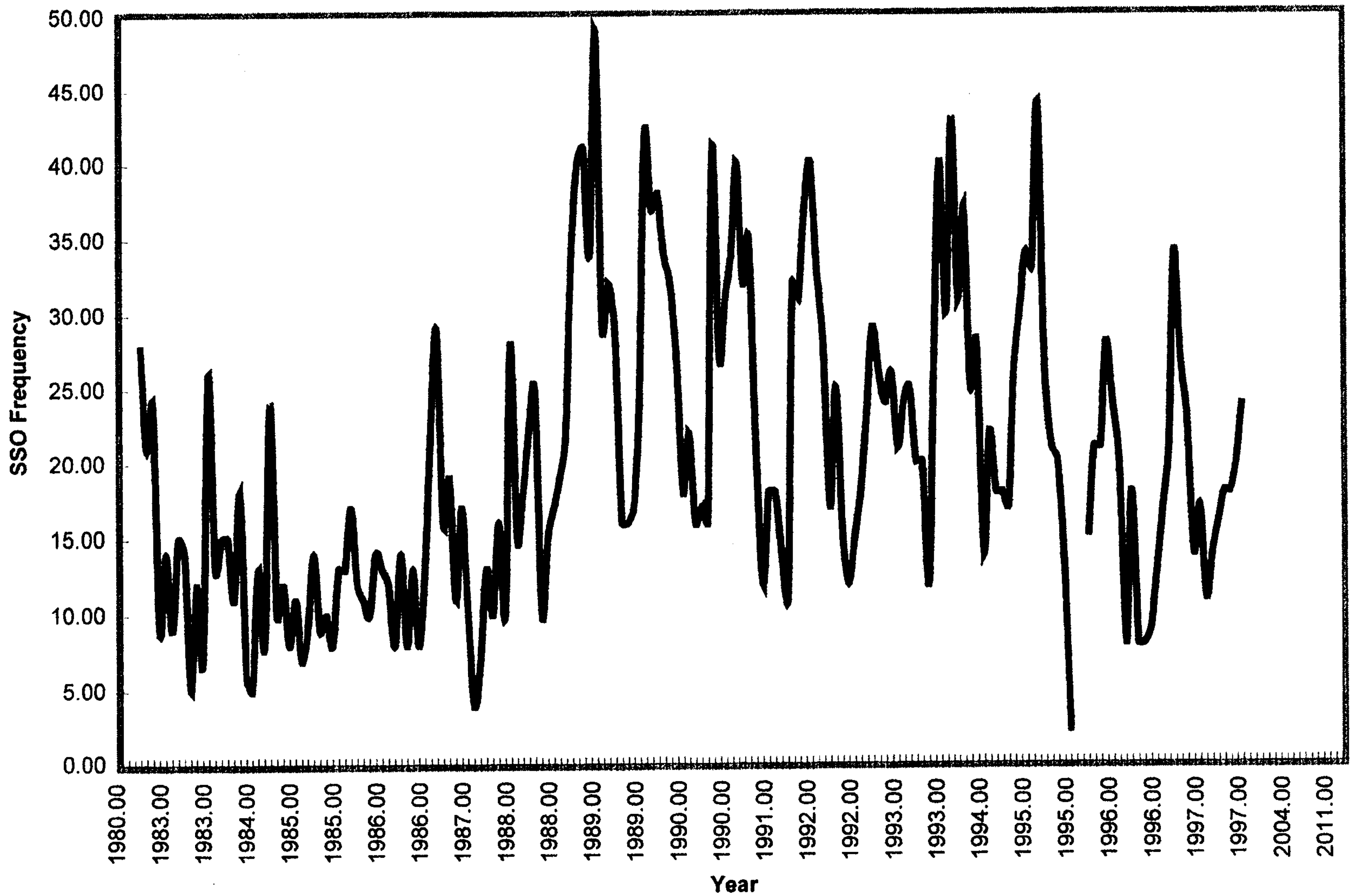


FIGURE 4: SSO Frequency, Observed vs. Estimated (Stage 2)

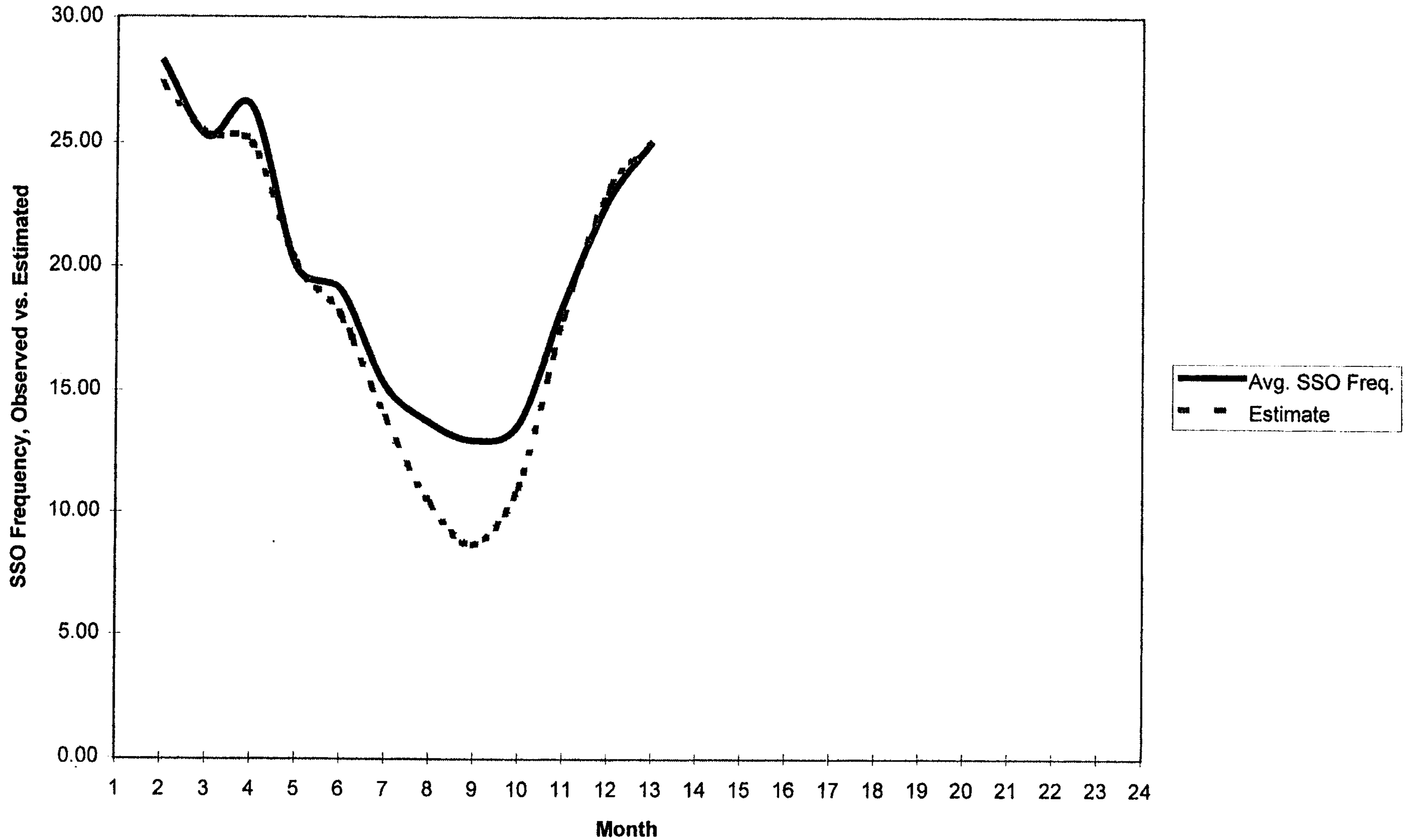


FIGURE 5: Flow Impact

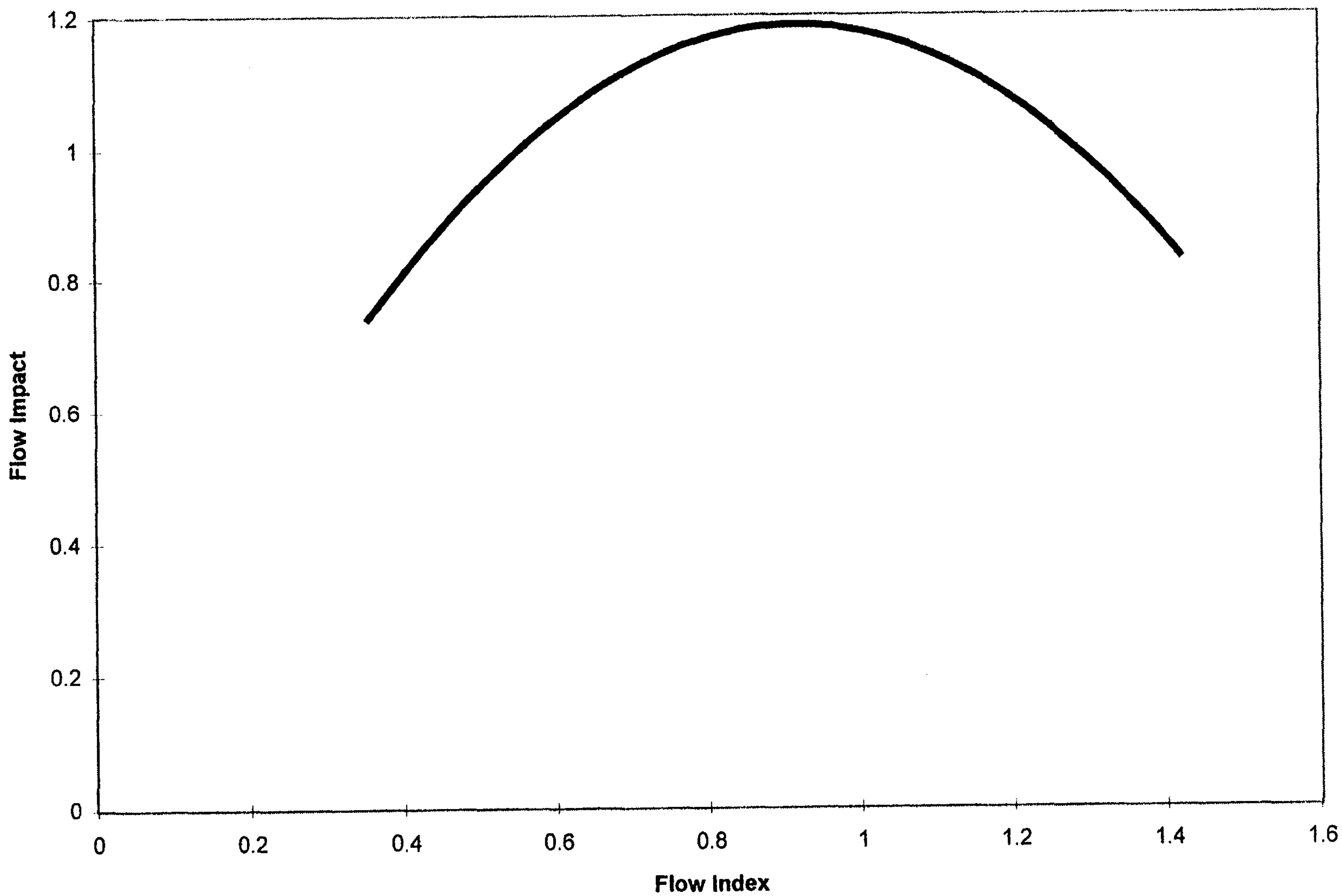


FIGURE 6: Seasonal Impact

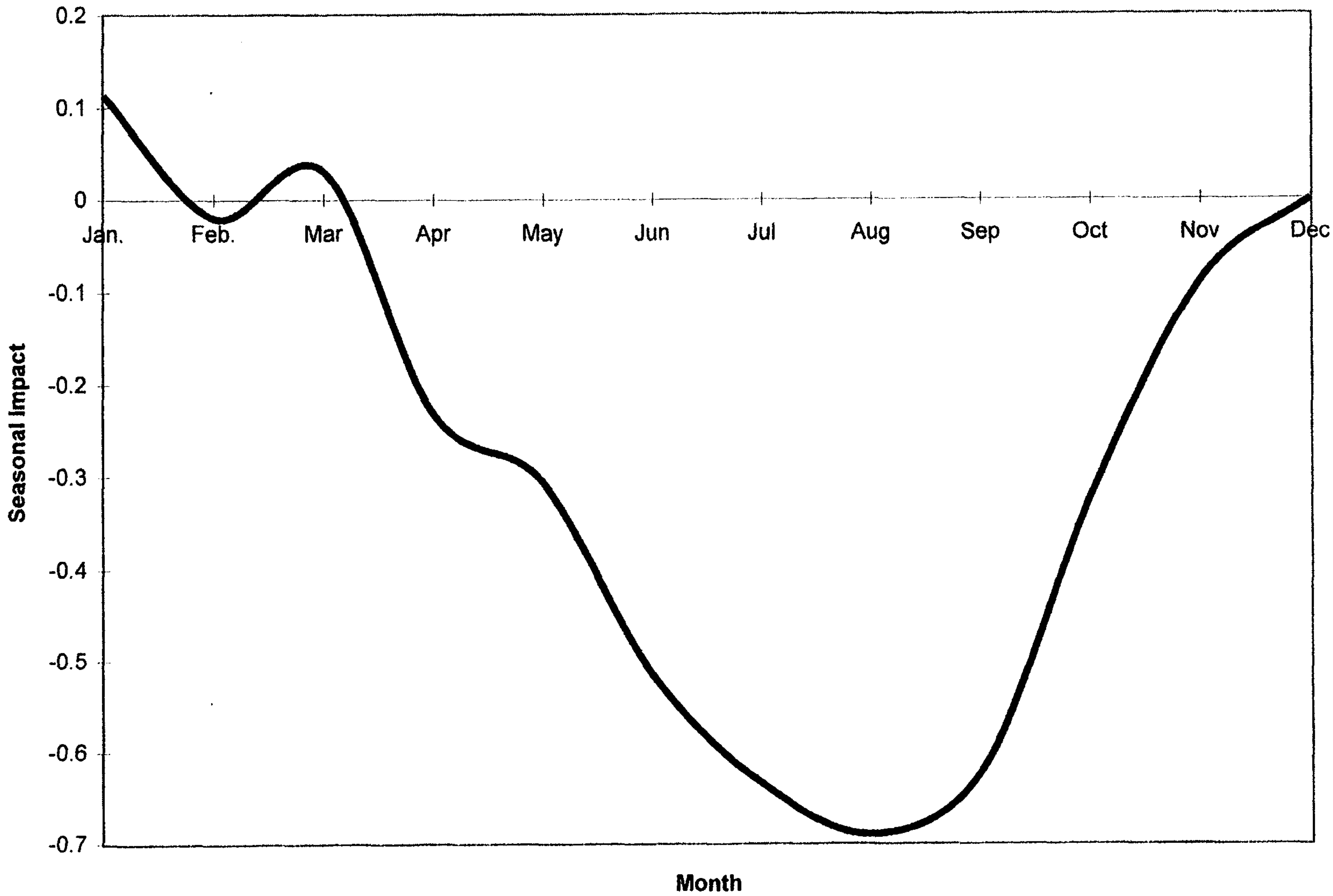


FIGURE 7: Pro-active Maintenance Impact